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CONTENTS

Cover Picture: The valley of upper Firth River near the Alaska-Yukon

Territory boundary, looking southwest, Mancha Creek in foreground, with aufeis to the left, June 1959.

Photo: John J. Koranda

Formation, Growth, and Decay of Sea-Ice. *Michael A. Bilello* 3

Geology of the Engigstciak Archaeological Site, Yukon Territory.

J. R. Mackay, W. H. Mathews, and R. S. MacNeish 25

The Transfer of Arctic Territories from Great Britain to Canada in 1880, and Some Related Matters, as Seen in Official Correspondence.

Gordon W. Smith 53

Notes:

University of Alaska Gulkana Glacier Expedition. *Troy L. Péwé* 74

A Study of Glacial Geomorphology in the Northern Torngat Mountains, Labrador. *Olav Løken* 75

Comments on "Carnivorous Walrus and Some Arctic Zoonoses".

T. H. Manning 76

Summer School Course in Eskimo Language and Culture at the University of Alberta 77

Institute News:

Gifts to the Library 78

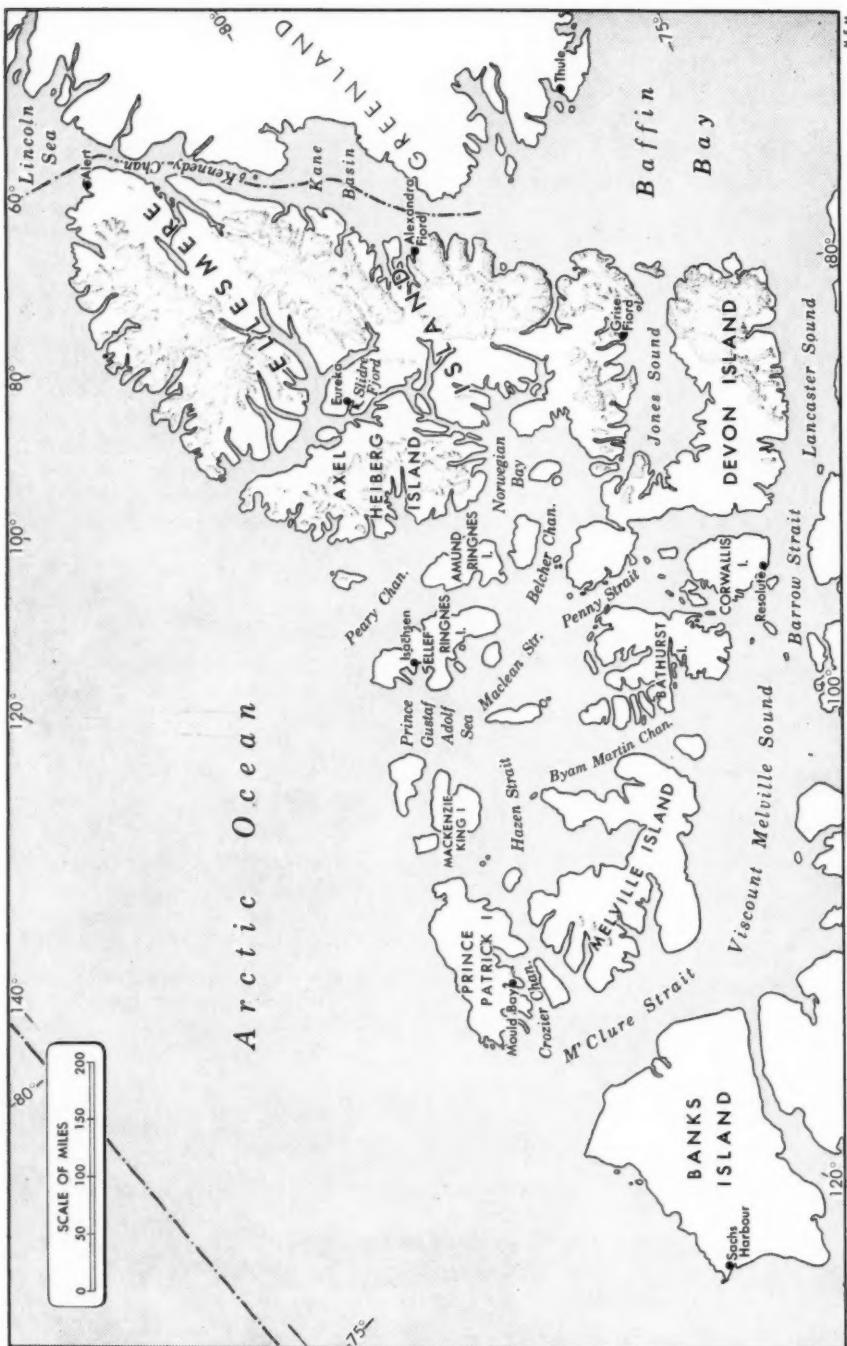
Annual Meeting of the Board of Governors 79

Man Living in the Arctic. *John C. Reed* 79

Review of the Arctic Environment. *John C. Reed* 80

Election of Fellows 80

Arctic Ocean



FORMATION, GROWTH, AND DECAY OF SEA-ICE IN THE CANADIAN ARCTIC ARCHIPELAGO

Michael A. Bilello*

Introduction

Various stages in the growth of sea-ice are mainly dependent upon the meteorological elements. Relationships between weather and ice conditions may provide methods for predicting ice formation, growth, and decay. This report is concerned with studies that associate formation and decay of sea-ice with air temperatures, and its rate of accretion with air temperatures and snow depths.

Investigations usually indicate that air temperature, snow depth, and initial ice thickness are the most important data required to predict the thickening of the ice sheet. Most formulas derived empirically (Bydin 1933, Lebedev 1938) express the vertical growth of sea-ice as:

$$I = a (\Sigma \theta)^b$$

where:

I = ice thickness

$\Sigma \theta$ = sum of negative daily air temperature

a and b = constants.

In part, the constants in the equation represent the influence of average snow conditions on the rate of ice growth. The effect of non-uniform or fluctuating snow depths on ice growth is not considered in equations of this type.

In this report, equations relating the accretion of sea-ice to standard meteorological data are derived empirically from observations made at stations located in the Canadian Arctic. The equations differ from existing formulas in that (1) they are differential in form, to permit the calculation of ice growth by increments, and (2) they contain a separate term that allows for variations in snow depth.

The methods applied to predict freeze-up were derived from a study of the relationship between ice formation in the Baltic Sea and weighted mean daily air temperature (Rodhe 1952).

The data used in this report were obtained from five localities in the Canadian Arctic Archipelago (Queen Elizabeth Islands) (Fig. 1). The meteorological observations and snow depth-ice thickness measurements were made by personnel assigned to these stations by the U. S. Weather Bureau

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and the Meteorological Branch, Canada Department of Transport. The stations and the years for which data on ice growth are available are as follows:

Alert, N.W.T.	1950-1 to 1952-3, and 1954-5 to 1956-7
Eureka, N.W.T.	1947-8 to 1951-2, 1953-4, 1954-5 and 1956-7
Isachsen, N.W.T.	1948-9 to 1952-3, and 1954-5 to 1956-7
Mould Bay, N.W.T.	1949-50, 1951-2, and 1953-4 to 1956-7
Resolute, N.W.T.	1947-8 to 1956-7

The location of each station, the names of surrounding water bodies and the approximate water depths where the ice thickness measurements were made are listed in Appendix A.

Sea-ice formation

The term "freeze-up" as used in this paper defines the date when ice first forms. When the body of water becomes completely covered with ice, the term "freeze-over" is used. The observers at the stations often found it difficult to determine correct dates of ice formation to fit the terms. For example, an observer at Alert, Mould Bay, and Eureka pointed out that during the falls of 1951 and 1954 it was practically impossible to establish firm dates for freeze-up and freeze-over. He found that sudden squalls and strong tidal currents in small bodies of water affect freeze-over considerably. Excerpts from a diary kept during August and September at these stations were submitted to bear out the unstable ice conditions. Except during unusual wind or current conditions, freeze-over generally occurred soon after freeze-up. The longest intervals were observed at Resolute Bay.

The available observed dates of freeze-up at the arctic weather stations are given in Table 1. Most of the observations were obtained as a part of the program for measuring sea-ice thickness. A search through Miscellaneous Notes (Records of Meteorological Observations, Canada Department of Transport) provided additional information, but the record for dates of freeze-up at these stations is still not complete.

Freeze-up at Resolute Bay in the 9 years of record occurred between September 12 and 26. Reports of rough ice and the occasional break-up of new ice in Resolute Bay indicate that a considerable amount of ice movement can occur at this locality during the period of ice formation.

At Eureka air temperatures were observed to decrease rapidly during September (U. S. Weather Bureau, Climatological Summary, Eureka). This rapid change accompanied by light winds results in a well defined freeze-up and comparatively smooth ice surface conditions. For the six years of available record, freeze-up on Slidre Fiord at Eureka was observed between September 6 and 21.

Table 1. Observed freeze-up dates, accumulated degree-days of frost (below $-1.8^{\circ}\text{C}.$) and frost-days.

Station	Year	Beginning date of continuous frost (below $-1.8^{\circ}\text{C}.$)	Observed freeze-up date	Number of frost-days (Column 4 minus column 3)	Accumulated degree-days of frost (below $-1.8^{\circ}\text{C}.$)
Alert	1956	Aug. 21	Aug. 27	6	9.1
	1954	Sept. 13	Sept. 17	4	12.8
	1952	Aug. 27	Aug. 30	3	15.2
	1951	Aug. 28	Aug. 31	3	12.4
			Mean =	4	12.4
Eureka	1956	Aug. 29	Sept. 6	8	17.3
	1954	Sept. 15	Sept. 21	6	19.3
	1953	Sept. 5	Sept. 13	8	23.8
	1951	Sept. 6	Sept. 13	7	16.2
	1950	Sept. 3	Sept. 7	4	14.5
	1947	Sept. 3	Sept. 15	12	16.7
Isachsen	1956	Aug. 21	Aug. 29	8	12.8
	1952	Aug. 27	Aug. 29	2	5.3
	1951	Sept. 3	Sept. 6	3	11.3
	1950	Sept. 3	Sept. 5	2	5.3
	1948	Aug. 20	Aug. 24	4	8.3
			Mean =	3.8	8.6
Mould Bay	1956	Aug. 26	Sept. 1	6	16.0
	1955	Aug. 31	Sept. 7	7	4.7
	1951	Sept. 10	Sept. 15	5	6.0
	1948	Aug. 26	Sept. 1	6	9.1
Resolute			Mean =	6	9.0
	1956	Aug. 28	Sept. 12	15	36.3
	1955	Sept. 9	Sept. 23	14	41.6
	1954	Sept. 14	Sept. 26	12	11.7
	1953	Sept. 6	Sept. 20	14	43.7
	1952	Aug. 28	Sept. 17	20	37.4
	1950	Sept. 12	Sept. 21	9	48.3
	1949	Sept. 7	Sept. 15	8	41.1
	1948	Sept. 12	Sept. 18	6	26.3
	1947	No temp. data for Sept.	Sept. 20	12.2	No temp. data for Sept. 35.8
			Mean =	12.2	35.8

In 1954, freeze-up at Resolute, Eureka, and Alert occurred unusually late in September. This delay apparently was associated with the abnormally high air temperatures observed throughout the Canadian Arctic Archipelago during that month (Fig. 2), and implies that any precise prediction of ice formation for this area may be largely dependent on the accuracy in forecasting the air temperatures during September.

Sea-ice in the bays at Isachsen, Mould Bay, and Alert does not always completely melt or drift clear in the summer. However, areas of open water do develop around these stations and freeze-up applies to formation of new ice over these areas. The precise effect of old ice on the formation of new ice could not be determined. It appears that fewer degree-days of frost are

required for freeze-up where old ice is present than at stations where ice completely melts or drifts away in the summer. This difference is probably due to lower water temperatures where old ice is present.

Freeze-up at Alert and Isachsen occurs as early as the last week of August. Except for unusually warm Septembers, as at Alert in 1954, freeze-up at these stations can be expected by September 8. At Mould Bay freeze-up occurred in the first 15 days of September during the years of record.

Few descriptions of the surface smoothness of newly formed ice sheets are contained in the records. Personal observation and conversation with station personnel indicate that surface smoothness varied to some extent for each year and location. Depending on the bulk of pack ice, and the direction and velocity of the wind during freeze-up, the bays and fiords may be clear or partly filled with bergs, old floes, rafted ice, etc. Tides and currents also disrupt thin ice sheets. In time, a cover of snow may hide small hummocks and minor cracks in the ice. A snow cover may create the impression (especially from the air) that the ice surface is smooth.

Methods for predicting freeze-up using air temperatures

Lee and Simpson (1954) present a method of predicting sea-ice formation that requires considerable climatological and oceanographic data for the area in question. Since such data are not generally available, this study was directed toward methods that might establish a suitable relationship between ice formation and air temperatures only.

Fukutomi (1950) developed an equation relating the freezing date of coastal waters in cold areas to air temperatures. In a later report (1955), he found the equation to be approximately applicable in specific cases, but the general value of part of the expression varied slightly for the Okhotsk, Japan, and arctic seas. The method was tested using data from the five stations covered in this study and was found to be applicable where approximate mean dates of freeze-up are required and only mean monthly air temperatures are available.

Ostman and Nusser as reviewed by Rodhe (1952) related sea-ice formation in the Baltic Sea and the Gulf of Bothnia to air temperatures. Ostman obtained the summation of degree-days of frost below 0°C . (numerical accumulation of differences between the mean daily air temperatures and a selected base), beginning with the first frost in fall or early winter, and correlated this "frost-sum" with ice formation in the adjacent sea. However, temperatures above 0°C ., which may intervene before ice formation begins, are not taken into consideration. Nusser correlated ice formation to the number of days with mean temperatures below 0°C . (frost days) which immediately preceded the date of occurrence. If the series of days was interrupted by only one day having a mean temperature of 0°C . or above, the day was then omitted. If the interruption consisted of two or more days, then the series of frost days before and after were considered as two differ-

ent frost periods and the first one was disregarded. The method, consequently, does not indicate for certain whether a particular frost period will produce ice.

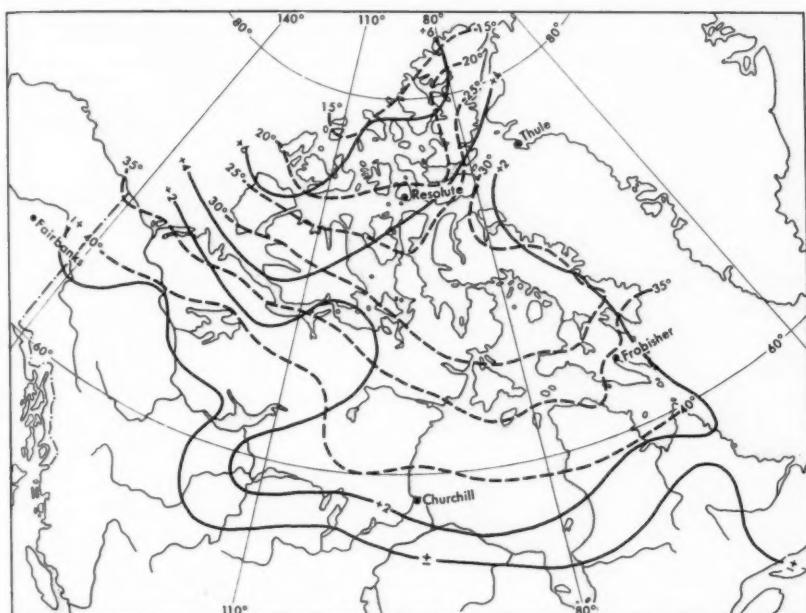


Fig. 2. Departure from mean monthly air temperature (°F.) for September 1954. Dashed lines are the mean monthly values, solid lines are the departures (from: April 1954).

These "frost-sum" and "frost-days" methods were combined and applied to data from the stations used in this study. The accumulated degree-days of frost and the number of frost-days (up to the time of freeze-up) are given for each station (Table 1). The mean values for each station are compared (Fig. 3). The diagram shows the average degree of coldness and the length of time required for ice to form at each station, but does not show the starting date of the effective frost period nor the effect of intervening periods of above-freezing temperatures. Since the water salinity in the area, if no ice is present, is about 32.0 to 33.0‰, -1.8°C . was used as the freezing point. (Sverdrup *et al.* 1942).

Rodhe (1952) presents a relationship between weighted mean daily temperature and ice formation, which does not depend solely on temperatures during a limited period of time. The mathematical theory is logically based upon a simplified physical law of heat flow between the sea surface and the air. The results of the investigation provide a method by which the date of ice formation at a particular locality can be computed objectively from daily air temperatures. The procedure is to determine by trial and

error which value of k^{-1} , using the expression $1 - e^{-k}$, provides the correct numerical sequence that must attain the value -1.8°C . on the exact day freeze-up occurred. By associating the time when the sequence reduces to -1.8°C . (or 0°C . for fresh water) with the dates of previously observed freeze-up, k^{-1} , termed the "Z" function, is determined for each location.

For example, let $k^{-1} = 20.0$, then $e^{-k} = e^{-0.05} = 0.951$, and $1 - e^{-k} = 0.049$. Initially a mean daily or monthly temperature that occurred at a period some months before freeze-up is selected (the mean monthly air temperature for June was used as the starting point in this study). This initial value is subtracted from the mean daily air temperature for the following day. The difference (which can be plus or minus) is multiplied by the constant 0.049. This weighted correction is then added arithmetically to the initial value. The adjusted value is then subtracted from the mean daily air temperature for the next day, and the difference is again multiplied by 0.049. The new correction is applied to the adjusted value and the procedure repeated. The computation in effect weighs each daily air temperature gradually, incorporating the influence of warm or cool summers and sudden cold or warm periods prior to freeze-up.

A sample computation follows where $k^{-1} = 20.0$ and the starting temperature = $+3.0^{\circ}\text{C}$.

A Date	B Mean daily air temp. $^{\circ}\text{C}$.	C (B - E)	D (C x 0.049)	E (E + D)
Mean for month of June				$+3.00^{\circ}\text{C}$.
July 1	+5.5	+2.50	.12	+3.12
2	+8.2	+5.08	.25	+3.37
3	+2.6	-0.77	-.04	+3.33
4	+6.0	+2.67	.13	+3.46

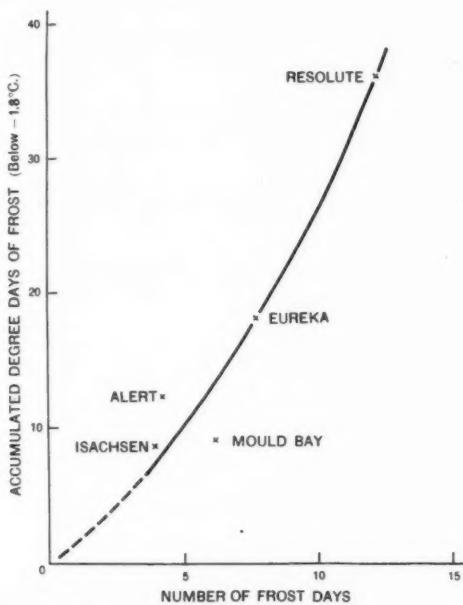
The computation continues up to the reported date of freeze-up. If on that date the value in column E is equal to the freezing point of the water then the "Z" function for that locality is equal to 20.0. If the value in column E is higher than the freezing point, then "Z" is decreased to alter the rate of change in column E. In order to obtain greater certainty in the value of "Z", it may be necessary to use 2 or 3 years of record when freeze-up occurred at a particular place. When "Z" has been determined, reasonably accurate prediction of freeze-up date becomes only a matter of good air temperature forecasts. A full mathematical treatment of the theory is available in Rodhe's Report (1952).

The following are the computed values for "Z" based on the freezing point of -1.8°C . for the five stations in this study:

Station	"Z" function
Alert	10.6
Eureka	9.9
Isachsen	8.4
Mould Bay	9.9
Resolute	21.0

Except for two cases in 25 station-years of record used in the above analysis, the "Z" functions shown yielded freeze-up dates correct to within 3 days of the observed dates (Table 2). Although the method is obviously still dependent upon the prognosis of air temperature, the task of predicting ice formation has been successfully limited to a single variable.

Fig. 3. Association of accumulated degree-days of frost (below -1.8°C .) and "frost-days".



Growth of sea-ice

The techniques used to measure sea-ice thickness (App. B) require that the observer walks out on the ice. First reports each year therefore depended upon shore conditions, ice strength, whether vehicles were being used, and the courage of the observer. Few observations for thicknesses less than 10 cm. were made, and reports usually were not received until approximately 20 cm. of ice had accumulated. The frequency of observations varied from year to year. Weekly observations provided smooth ice-growth curves, whereas monthly readings produced flat, poorly defined curves. Another advantage of the more frequent observations was that erroneous measurements were readily detected.

Observations on ice thickness and snow depth were made in a general region rather than at exact localities. Large discrepancies did not result from this practice unless there were appreciable differences in the depth of snow, or parts consisting of old or rafted ice were unintentionally being measured.

It became apparent after drawing the accumulative ice curves that some adjustments would be necessary for general smoothness. It was decided to

tolerate a ± 10 cm. correction for individual observations, but to maintain a maximum of ± 10 cm. adjustment for the mass curve.

Using the ice thickness data obtained at each station, smooth curves for ice growth were drawn. The maximum seasonal growth of ice was observed at Isachsen, where 269 cm. was measured in April 1950; the minimum was 149 cm. at Resolute measured in April-May 1953 (Fig. 4). Corresponding snow depths are also shown in Fig. 4. The amount of ice that accumulates differs from year to year, as well as from station to station. These differences are the result of variations in tides, currents, other oceanographic conditions, and numerous meteorological processes. The lack of data for most of these parameters however made it necessary to confine the study to an analysis of the effect of air temperatures and snow depths on the growth of sea-ice. These meteorological variables are the ones most readily obtained from regularly scheduled teletype transmissions, thus permitting application of the equation to currently available data.

Table 2. Observed versus computed freeze-up dates.

Station	Year	Observed freeze-up date	Computed freeze-up date
Alert	1956	Aug. 27	Aug. 30-31
	1954	Sept. 17	Sept. 16
	1952	Aug. 30	Aug. 29-30
	1951	Aug. 31	Aug. 31
Eureka	1956	Sept. 6	Sept. 6
	1954	Sept. 21	Sept. 21
	1953	Sept. 13	Sept. 11-12
	1951	Sept. 13	Sept. 12
	1950	Sept. 7	Sept. 10
	1947	<i>August temps. missing</i>	
Isachsen	1956	Aug. 29	Aug. 28
	1952	Aug. 29	Aug. 29
	1951	Sept. 6	Sept. 5
	1950	Sept. 5	Sept. 5
	1948	Aug. 24	Aug. 24
Mould Bay	1956	Sept. 1	Aug. 31
	1955	Sept. 7	Sept. 7
	1951	Sept. 15	Sept. 16
	1948	Sept. 1	Sept. 1
Resolute	1956	Sept. 12	Sept. 12-13
	1955	Sept. 23	Sept. 20-21
	1954	Sept. 26	Sept. 29-30
	1953	Sept. 20	Sept. 20
	1952	Sept. 17	Sept. 18
	1950	Sept. 21	Sept. 20
	1948	Sept. 18	Sept. 20
	1947	<i>September temps. missing</i>	

The cumulative degree-days of frost as related to the growth of ice were computed using a base of -1.8°C . Mean daily air temperatures were computed from the maximum and minimum temperatures for the day. As daily air temperatures at these high-latitude stations rarely go above

—1.8°C. (after freeze-up), the effect of intervening thaw periods on ice growth can be neglected.

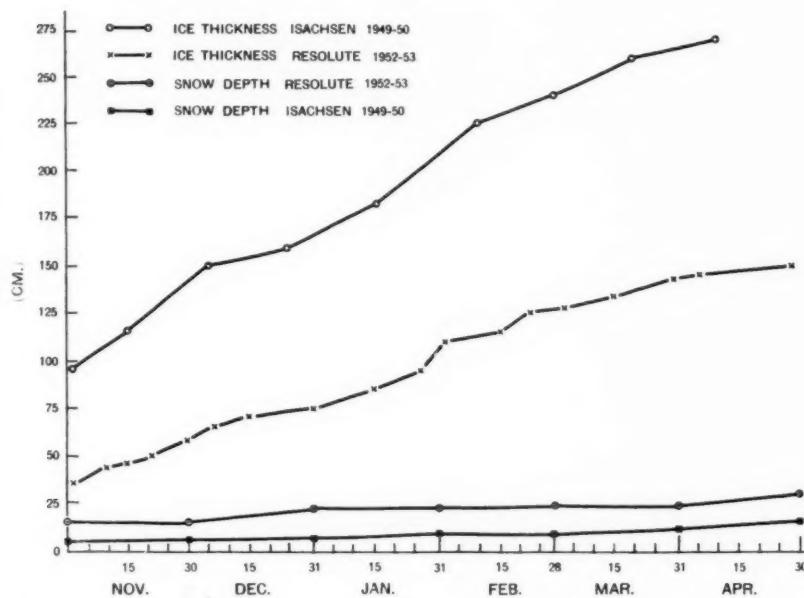


Fig. 4. Maximum and minimum sea-ice growth curves.

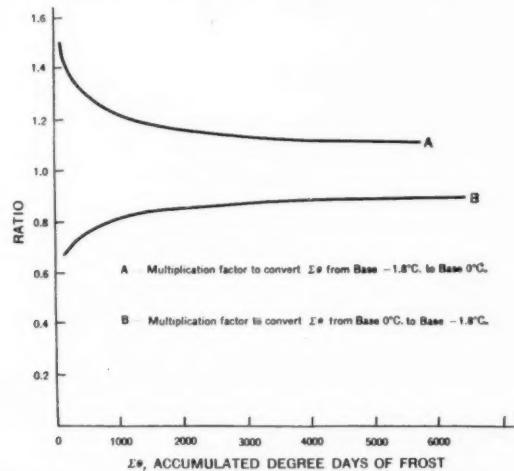


Fig. 5. Conversion of accumulated degree-days of frost using the base of 0°C. or —1.8°C.

Accumulated degree-days of frost for most of the published studies on ice growth were computed using a base of 0°C. To facilitate computation or to make comparisons possible, direct conversion from the 0°C. base to —1.8°C. or vice versa may be obtained from the ratio curves shown in

Figure 5. These ratios, however, are applicable only as an average for the Canadian stations discussed in this report.

The average winter accumulation of degree-days of frost is plotted in Figure 6 for each station. Up to the end of May the curves show Eureka as having the largest (6830) and Resolute the smallest (5680) average accumulation. Year to year variations in accumulated degree-days of frost at each station would influence the total amount of ice that accumulates.

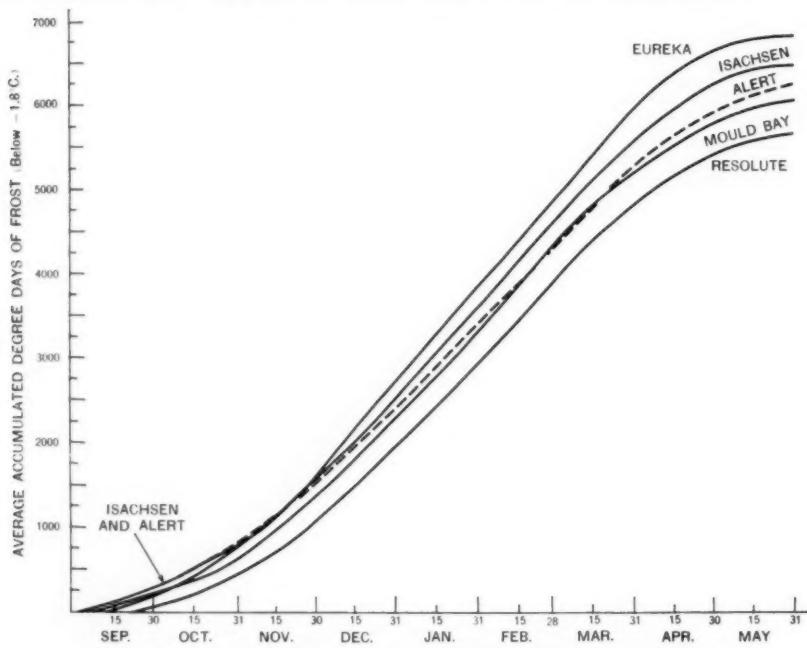


Fig. 6. Average accumulated degree-days of frost (below $-1.8^{\circ}\text{C}.$).

Figs. 7-11, a series of smooth curves for each station, show the thickness of sea ice as related to accumulated degree-days of frost and depth of snow on the ice. Data on snow were either missing or incomplete for some periods of the record. To supplement the data, information on depth of snow on the ground and daily snowfall amounts was obtained from the Monthly Record, Meteorological Observations in Canada (Department of Transport). The marked effect of snow cover on ice growth forms the basis for the derivation of an ice-growth equation, (8), which contains a separate term to allow for variations in snow depth.

Equations for predicting sea-ice growth using air temperatures

Callaway (1954) analyzes the numerous variables in equations developed by Kolesnikov (1946) and evaluates their separate effects. The results, in part, point out the pronounced effect of air temperature, snow thickness, and ice thickness on the rate of ice accumulation.

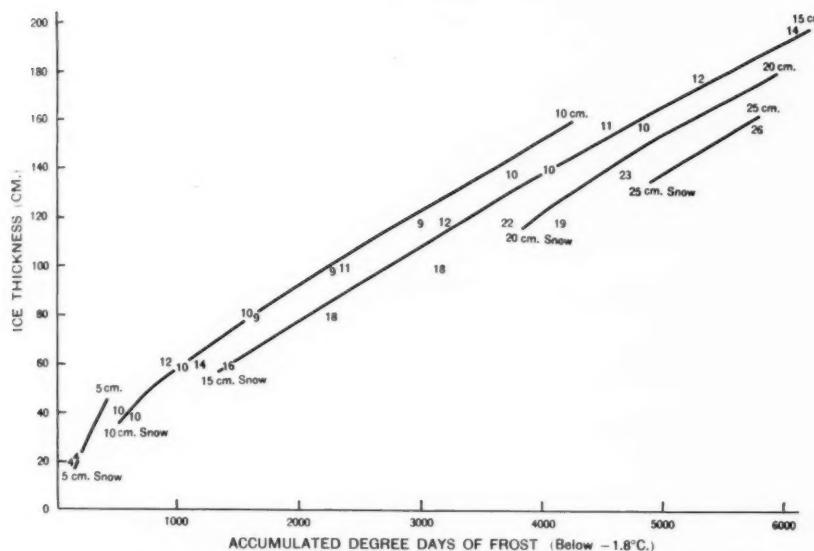


Fig. 7. Relationship between ice thickness, accumulated degree-days of frost (below -1.8°C .) and snow depth (numbers on curves) at Alert.

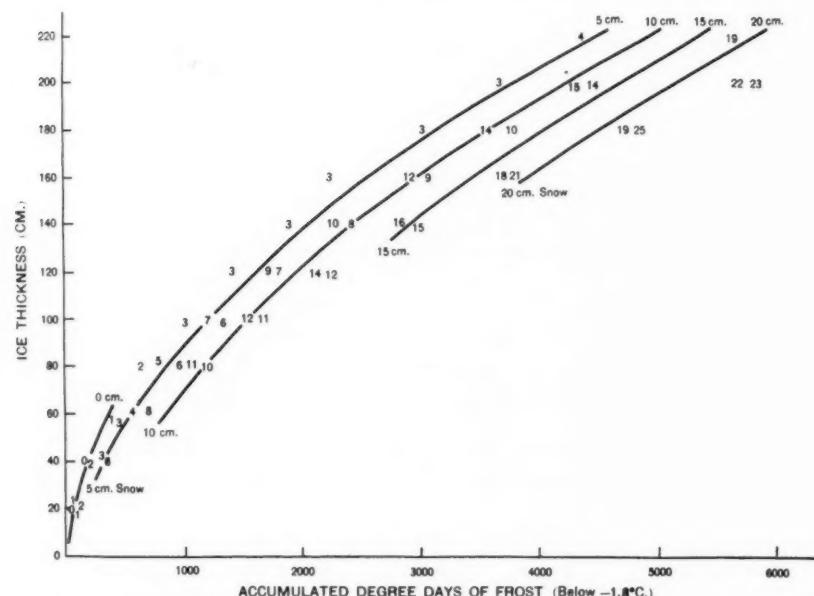


Fig. 8. Relationship between ice thickness, accumulated degree-days of frost (below -1.8°C .) and snow depth (numbers on curves) at Eureka.

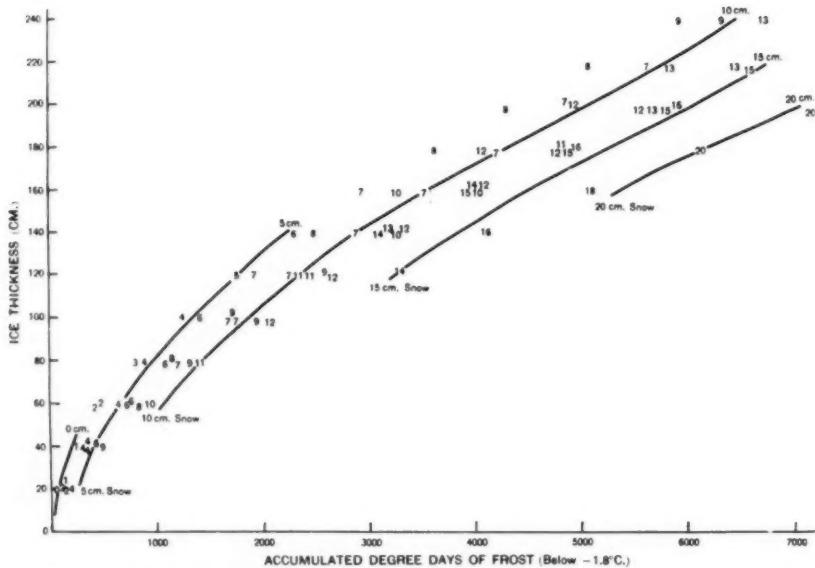


Fig. 9. Relationship between ice thickness, accumulated degree-days of frost (below $-1.8^{\circ}\text{C}.$) and snow depth (numbers on curves) at Isachsen.

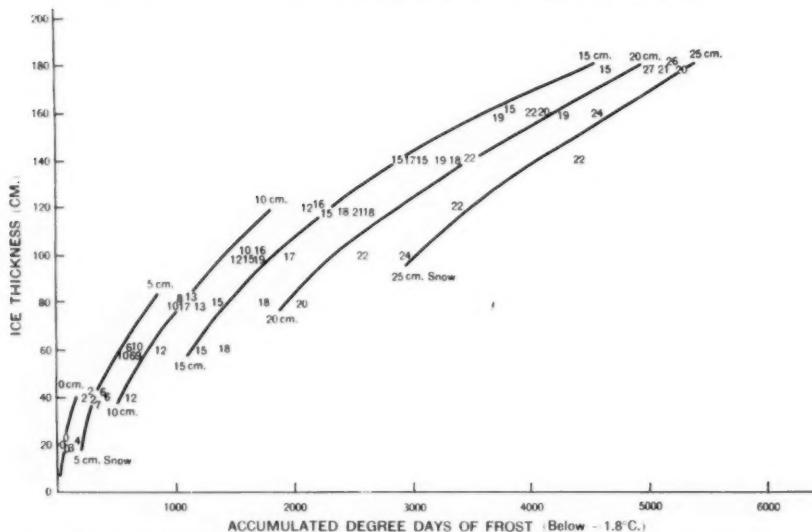


Fig. 10. Relationship between ice thickness, accumulated degree-days of frost (below $-1.8^{\circ}\text{C}.$) and snow depth (numbers on curves) at Mould Bay.

V. V. Lebedev (1938) summarizes the results of several authors. The review includes theoretical expressions by Stefan and Tamura that exclude

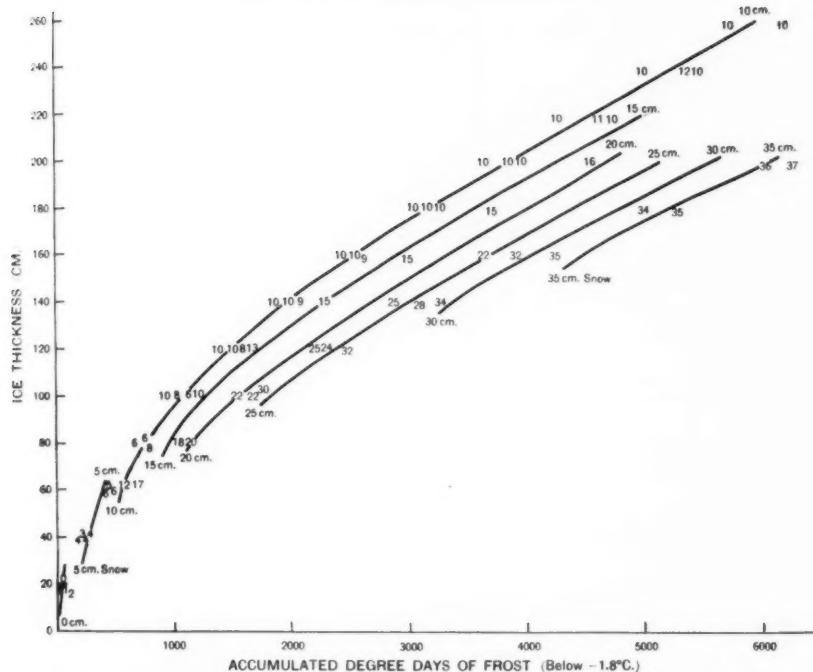


Fig. 11. Relationship between ice thickness, accumulated degree-days of frost (below $-18^{\circ}\text{C}.$) and snow depth (numbers on curves) at Resolute.

the effect of a snow cover, and empirical equations by Karelín, Zubov, and others that take average snow conditions into account but make no attempt to evaluate its effect separately.

Using 19 stations in the Kara, East Siberian, Chukhotsk, Barents and Laptev seas for 24 station-years of observation, Lebedev found that the accretion of sea-ice (under average snow conditions) was related to the sum of negative mean daily air temperatures as follows:

$$h = 1.33 (\Sigma \theta)^{0.58} \quad (1)$$

where: h = thickness of ice in cm. and

$\Sigma\theta$ = sum of negative air temperatures (below 0°C.)

An equation of the same form:

$$h = 1.53 (\Sigma \theta)^{0.59} \quad (2)$$

fits data obtained by Graystone (personal communication) in Button Bay near Churchill, Canada, when snow cover was negligible.

Curves representing these equations, as well as Zubov's (1945) expression

$$h^2 + 50 h = 8 \Sigma \theta \quad (3)$$

for stations in the Kara and Chukhotsk seas, and a composite curve for the five Canadian arctic localities in this study were compared (Fig. 12). Although derived from data for different areas the curves show similar shape.

The average seasonal snow depth observed at the stations in this study is shown in Fig. 12.

Lebedev (1938) also introduces the formula:

$$h = (1.245) (\Sigma \theta)^{0.62} (h_s)^{-0.15} \quad (4)$$

which defines the dependence of ice accretion h on negative air temperatures $\Sigma \theta$ (below 0°C .) and the thickness of snow on the ice h_s in cm. Equation (4), however, was based on the data for only one year for fresh-water ice from the Yana River at Kazach'ye and the Kolyma River at Konzoboy in north-eastern Russia.

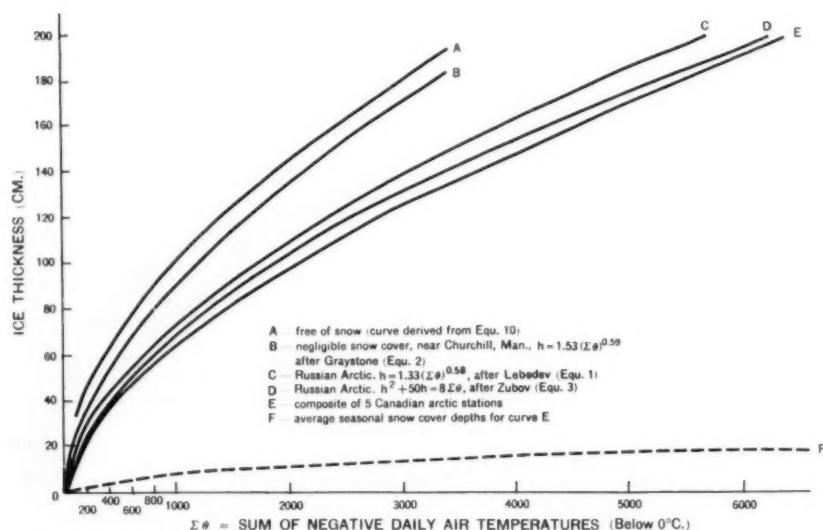


Fig. 12. Comparison of separate studies on accretion of sea-ice versus sum of daily negative air temperatures (below 0°C).

Assur (1956) presents the relation:

$$h = (K) 1.06\sqrt{S} \quad (5)$$

where:

h = ice thickness in inches,

K = coefficient, considering snow cover, stream flow, and other local conditions,

S = accumulated degree-days of frost since freeze-up (below 32°F).

This equation was developed for fresh-water ice but applied also as a first approximation for sea-ice.

The above equations permit the prediction of ice growth using air temperatures only, but no provision is made to compute increments of ice and no allowance is made for variations in snow depth.

A method for predicting sea-ice growth by increments using air temperatures and snow depths

Assur presents an equation for computing increase of ice thickness in small increments, considering the insulating effect of different types of snow. (Assur 1956, eq. (4), p. 18). This equation expressed in simple terms for operational needs is actually a differential equation, which can be easily derived and modified for use as follows (personal communication).

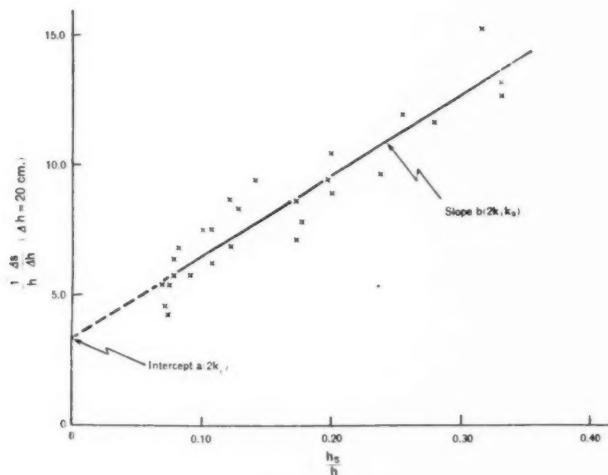
As a first approximation from equation (5):

$$h^2 = kS, \quad (6)$$

differentiating produces $2h dh = k dS$ and setting $1/k = k_i$,

$$\frac{dS}{dh} = 2k_i h. \quad (7)$$

Fig. 13. Regression to obtain $2k_i$ and $2k_i k_s$ for Alert.



The change in ice thickness with respect to accumulated degree-days of frost at this point is dependent only upon ice thickness h . A snow layer of the thickness h_s can be considered in its insulating effect as an equivalent ice layer $k_s h_s$, and

$$\frac{dS}{dh} = 2k_i (h + k_s h_s) \quad (8)$$

It is convenient to express (8) as

$$\frac{1}{h} \cdot \frac{dS}{dh} = 2k_i + 2k_i k_s \cdot \frac{h_s}{h} \quad (9)$$

and then to plot $\frac{1}{h} \cdot \frac{dS}{dh}$ against $\frac{h_s}{h}$. The coefficients are obtained

from the slope, $b = 2k_i k_s$, and the intercept, $a = 2k_i$, of lines determined by least squares (Fig. 13). For ease of computing, differences (Δ) instead of differentials (d) were used. The terms are defined as follows:

$$\Delta S = \int_{t_1}^{t_2} \theta dt, \text{ accumulated degree-days of frost (below } -1.8^{\circ}\text{C.) during the periods of ice accretion.}$$

t = time in days,

$\Delta h = h_2 - h_1$, amount of ice accreted (cm.) during the time interval Δt . Intervals of 20 cm. of ice were found to be most adequate for the analysis,

$$h = \frac{h_1 + h_2}{2}, \text{ average thickness of the ice during accretion of } \Delta h \text{ (cm.) and,}$$

$$h_s = \frac{h_{s1} + h_{s2}}{2}, \text{ average thickness of the snow cover during accretion of } \Delta h \text{ (cm.).}$$

Table 3 gives the values for $2k_i$ and $2k_i k_s$, which are reduced to unity ($\Delta h = 1$ cm.).

Table 3. Values of $2k_i$ and $2k_i k_s$

	$a = 2k_i$	$b = 2k_i k_s$	$k_s = b/a$
Alert	0.168	1.561	9.3
Eureka	0.160	1.348	8.4
Isachsen	0.148	0.651	4.4
Mould Bay	0.164	0.976	6.0
Resolute	0.156	1.152	7.4

Simplifications introduced in the derivation of (5) do not allow its use for thin ice (from 1 to 20 cm.). Insufficient observations also prevented a detailed study of the growth of thin ice.

It should be noted that b/a (or k_s) represents the relative insulating effect of snow in comparison to ice. These values are in good agreement with an investigation on thermal insulating effects of different types of snow cover on the ice by Assur (1956). Since the constant $2k_i$ is practically the same for all stations, accretion of sea-ice (except for thin sheets) that is free of snow is described approximately by the equation:

$$h^2 = 12.6 \Sigma \theta \quad (\text{using a base of } -1.8^{\circ}\text{C.}) \quad (10)$$

A graphical representation of the above using a base of 0°C. is shown in Figure 12.

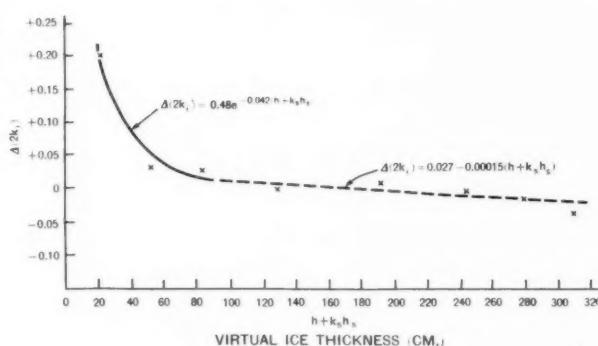
The differences in the constant k_s can be attributed to variations in the density of the snow and other meteorological and oceanographic differences between stations.

Substituting the values of $2k_i$ and k_s into equation (8) provides an expression in differential form in which a separate term for the depth of snow on an ice sheet is introduced. For example, Resolute:

$$dS = dh 0.156 (h + 7.4 h_s). \quad (11)$$

To study a possible effect of the ice thickness on $2k_i$ the differences between observed and computed points (Fig. 13) were plotted against the virtual ice thickness, $h + k_{sh_s}$. (Virtual ice thickness is the total relative insulating effect of the snow cover plus the ice sheet in terms of ice thickness. The relative insulating effect of snow, k_{sh_s} , is obtained from the last column in Table 3.). Fig. 14 shows the result. The points represent arithmetic means of about 20 values each for the 3 points up to 100 cm., about 50 values each for the 3 points up to 260 cm., and 35 values each for the 2 points above 260 cm. For virtual ice thicknesses greater than 90 cm., the straight-line formula $\Delta(2k_i) = 0.027 - 0.00015(h + k_{sh_s})$, obtained by

Fig. 14. Differences between observed and computed points of $2k_i$ versus virtual ice thickness ($h + k_{sh_s}$). $\Delta(2k_i)$ = departures of the observed values of $2k_i$ from the regression lines (e.g., Fig. 13).



least squares shows that no adjustments to the constant $2k_i$ are necessary. For virtual ice thicknesses between 20 and 90 cm., however, the correction $\Delta 2k_i$ to be added to the constant $2k_i$ in Table 3 is

$$\Delta(2k_i) = 0.48e^{-0.042(h + k_{sh_s})}. \quad (12)$$

Equation (12) was derived by a visual fit on a semi-log plot.

Decrease in sea-ice thickness and equations for predicting it using air temperatures

Few investigations have been made of the rate at which sea-ice decreases in thickness. Most of the literature on the subject relates to the break-up of rivers and lakes for navigational purposes (Zubov 1945, Burbidge and Lauder 1957). These studies are based on observations of deteriorating ice conditions rather than measurements of the decrease in ice thickness.

Theoretical equations similar to those available for sea-ice growth have not been developed for the decay process. The many physical and mechanical variables which affect sea-ice decay, and also lack of methods and instrumentation, apparently have prevented the investigation of the problem.

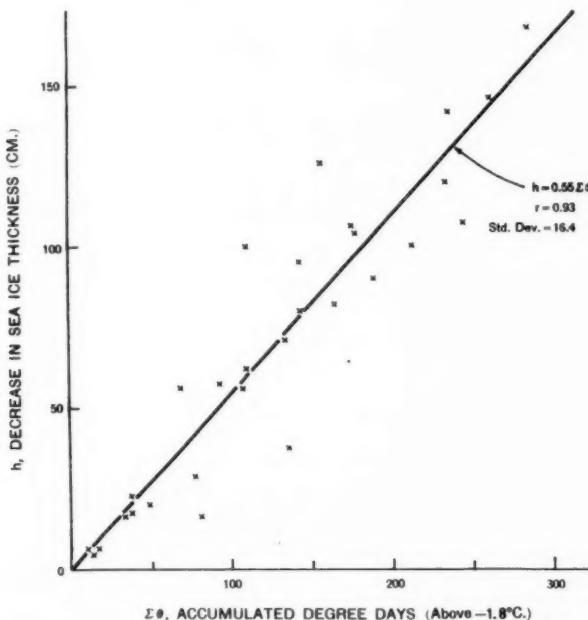
Table 4. Decrease in sea-ice thickness and accumulated degree-days (above $-1.8^{\circ}\text{C}.$)

Station	Year	Date	Ice thickness (cm.)	Total decrease in ice thickness (cm.)	Accumulated degree days (above $-1.8^{\circ}\text{C}.$)
Eureka	1951	June 1	231.1		
		June 18	212.1	19.0	57
		June 25	170.2	60.9	107
		July 2	127.0	104.1	174
		July 9	88.9	142.2	235
		July 17	63.5	167.6	286
	1950	June 5	261.6		
		June 16	238.8	22.8	40
		June 28	162.6	99.0	109
		July 4	137.2	124.4	155
1949	1949	May 15	255.3		
		June 16	198.1	57.2	91
		July 8	137.2	118.1	233
	1948	May 25	228.6		
Isachsen	1956	June 16	172.7	55.7	67
		May 2	203.2		
		July 22	132.1	71.1	132
		July 29	121.9	81.3	162
		Aug. 1	114.3	88.9	189
		Aug. 5	104.1	99.1	213
		Aug. 19	96.5	106.7	245
	1954	June 1	231.1		
		July 1	215.9	15.2	82
1951	1951	June 4	268.0		
		Aug. 4	121.9	146.1	262
	1948	May 14	213.4		
Mould Bay	1951	May 25	198.1	15.3	31
		June 11	221.1		
		June 13	215.9	5.1	9
	1948	July 9	127.0	94.0	142
		June 21	177.8		
Resolute	1955	July 16	139.7	38.1	125
		June 15	181.1		
	1954	June 20	178.1	3.0	14
		June 28	199.1		
		July 5	182.6	16.5	36
1950	1950	July 12	143.7	55.4	106
		July 20	120.9	78.2	141
		July 26	96.8	102.3	178
	1950	June 16	194.3		
		June 20	189.2	5.1	16
		July 4	162.6	31.7	80

No emphasis was placed on continuing ice thickness observations during the ablation period at the stations. However, sufficient measurements were made to justify an analysis of the relationship between the decrease of sea-ice thickness and air temperatures.

The observed decrease of ice thickness and concurrent accumulated degree-days are given in Table 4 for 4 of the stations in this study. Accumulated degree-days are obtained by summing the difference between -1.8°C . and each mean daily air temperature above -1.8°C . The base of -1.8°C . was used because it approximates the freezing point of the sea-ice in this area, and (as will be shown) statistically provides the best base for the analysis.

Fig. 15. Relationship between decrease in sea-ice thickness and accumulated degree-days (above -1.8°C .).



The 29 observations on decreasing sea-ice thicknesses are plotted against accumulated degree-days in Fig. 15. A least squares computation on the variables yielded a correlation coefficient of 0.93; and a standard deviation of 16.4 cm. The relationship is

$$h = 0.55\Sigma\theta \quad (13)$$

where: h = decrease in ice thickness (cm.), and

$\Sigma\theta$ = accumulated degree days above -1.8°C .

D. B. Karelina as quoted by Armstrong (1955) developed the formula

$$h = 0.51 (\Sigma\theta - 32) \quad (14)$$

where: h = thickness of ice thawed in cm., and

$\Sigma\theta$ = sum of average daily air temperatures over -5.0°C .

No information was presented on the quantity of data used in development of the empirical equation. The source of the data, as indicated by the reference title, apparently was in the Russian Arctic.

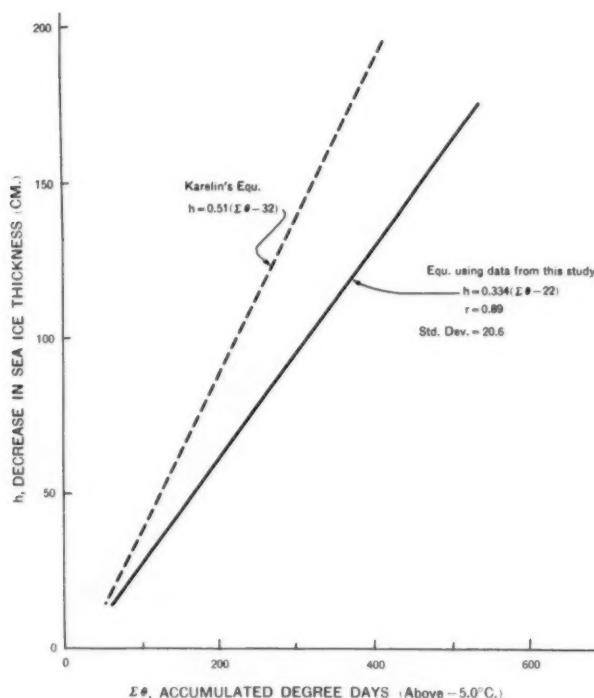


Fig. 16. Comparison of equations that associate decrease in sea-ice thickness with accumulated degree-days (above $-5.0^{\circ}\text{C}.$).

Employing the base of $-5.0^{\circ}\text{C}.$ used by Karel the data in this study gave the equation, determined by least squares,

$$h = 0.334(\Sigma\theta - 22). \quad (15)$$

Comparing this equation with Karel's (Fig. 16) reveals that the Canadian Arctic apparently requires more accumulated degree-days for increasing amounts of ice decay than the Russian Arctic. The results show also that a base of $-1.8^{\circ}\text{C}.$ yields a higher correlation coefficient than a base of $-5.0^{\circ}\text{C}.$ (0.93 against 0.89), and a smaller standard deviation (16.4 against 20.6 cm.).

Acknowledgements

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Appendix A

Areas and bodies of water studied:

Alert (82°30'N. 62°20'W.) is located on Parr Inlet in the northeast corner of Ellesmere Island, N.W.T., Canada. A narrow constriction separates Parr Inlet from Dumbell Bay. To the north of Dumbell Bay is the Lincoln Sea and the Arctic Ocean.

The ice thickness measurements were made at the center and occasionally at the mouth of Parr Inlet. The depth of water at about 200 metres off shore in Parr Inlet is approximately 14 metres.

Eureka (79°59'N. 85°57'W.) is on the northern shore of Slidre Fiord. The fiord runs east-southeastward from Eureka Sound, which is located between Axel Heiberg and Ellesmere islands (Fig. 1).

The ice measurements were made in Slidre Fiord at 150 to 300 metres from the shore line where the depth of water is between 23 and 61 metres.

Isachsen (78°47'N. 103°32'W.) is on Deer Bay on the west coast of Ellef Ringnes Island. Peninsulas that extend westward to the north and south of the station form this relatively large bay. To the southwest of Deer Bay is the Prince Gustaf Adolf Sea and to the northwest the Arctic Ocean.

The ice measurements were made in Deer Bay at 100 to 500 metres off-shore where the water is 12 to 30 metres in depth.

Mould Bay (76°14'N. 119°20'W.) is located on Mould Bay on the south-east coast of Prince Patrick Island. This bay runs north-south and is approximately 40 kilometres long and 6 kilometres wide. The bay opens into Crozier Channel to the south.

The ice measurements were made in Mould Bay at 150 to 800 metres off-shore where the water is from 6 to over 30 metres in depth.

Resolute (74°41'N. 94°54'W.) is on Resolute Bay on the southern coast of Cornwallis Island. To the southeast and southwest of Resolute Bay are the waters of Barrow Strait.

The ice measurements were made in Resolute Bay at 100 to about 875 metres from shore, where the depth of water is from 6 to 16 metres.

Appendix B

Techniques used to measure sea-ice thickness

During the first years of operation, ice thickness was measured through holes chipped out with chisels. On occasion dynamite was used to blast through the upper part of thick ice, and the hole was finished with chisels.

An electrical-mechanical method for measuring ice thickness was introduced by Polar Operations, U. S. Weather Bureau, in 1953-4, at the arctic stations. The apparatus consists of a portable power source and a wire loop going through the ice into the water below. The wire carries an umbrella shaped device under the ice sheet. Electric power is applied to heat the wire

which melts free, permitting it to be lifted until the umbrella device touches the bottom of the ice.

This method was used with success prior to 1956. In one case (Resolute, 1955-6), a wooden box was used to shelter the apparatus. The snow accumulation about this box was markedly different from the natural snow cover so no reliable analysis on ice growth could be made for that year.

To facilitate the making of these ice observations and to improve the accuracy of the measurements, a standard hand-operated ice auger developed by SIPRE was assigned to each station in April 1956. When proper precautions are applied, this auger permits drilling of a 1-inch hole through thick ice in a short time. To measure the ice thickness, a measuring tape with a short section of rod attached to its end is lowered into the hole. When the rod is below the ice sheet, it swings to a horizontal position. The rod is then lifted until it stops at the undersurface of the ice and the thickness of the ice is observed. A separate wire attached to the end of the rod is used to draw the rod and tape back through the hole.

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GEOLOGY OF THE ENGIGSTIAK ARCHAEOLOGICAL SITE, YUKON TERRITORY

J. R. Mackay,* W. H. Mathews,** and R. S. MacNeish***

FOR some years students of human history have hoped and expected to find a record of human occupation in the Arctic of western Canada and Alaska comparable in antiquity to the now rather numerous "Early Man" sites of the central and southwestern United States. The Engigstiaak site (discovered by MacNeish in 1954) near the mouth of the Firth River, Yukon Territory, Canada (Fig. 1), appears to contain such a record in the form of typologically old-looking flint artifacts intimately associated with the bones of extinct animals. The rich artifact assemblage also includes objects assignable on typological grounds to much later cultures, some of which are already well known in other parts of the Arctic. It is clear that the site has been occupied repeatedly throughout much of post-glacial time.

Unfortunately, the natural processes of soil movements of an arctic climate, acting upon especially frost-susceptible sediments, has almost completely destroyed the original stratigraphic relationships in some parts of the archaeological site. In a few places there has been an intimate mixing of soil particles, plant remains, and artifacts of diverse ages, and in other places the differential movement of older materials down-slope over younger materials has resulted in the reversal of the original stratigraphic sequence. Artifacts and bones of extinct and living animals have clearly been involved in the soil movements, so a close physical juxtaposition between a given artifact and a given bone fragment, or micro-fossil-bearing soil specimen, does not necessarily indicate a close age relationship. The problems are further complicated by the probability that a widespread marine silty clay covering the site arrived at its present position by glacial transportation from considerably lower altitudes.

Engigstiaak (new or youthful mountain in Eskimo), from which the site derives its name, is a low but rugged eminence in the foothills of the British Mountains, the eastern extension into the Yukon Territory of the

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Brooks Range of Alaska (Fig. 1). Its summit (Fig. 2), about 575 feet above sea-level, provides an unobstructed view northeasterly across the tundra-covered coastal plain to Herschel Island and the Arctic Ocean, southeasterly and northwesterly (Fig. 8) across several miles of barren lowlands to its nearest neighbouring foothills, and southwesterly up the treeless valley floor of Firth River toward the 5000-foot peaks of the British Mountains. A few hundred feet west of this lookout is a small rounded plateau summit (altitude 480 feet), which drops sharply northward and westward to the level of Firth River, and southward somewhat less abruptly to the highest

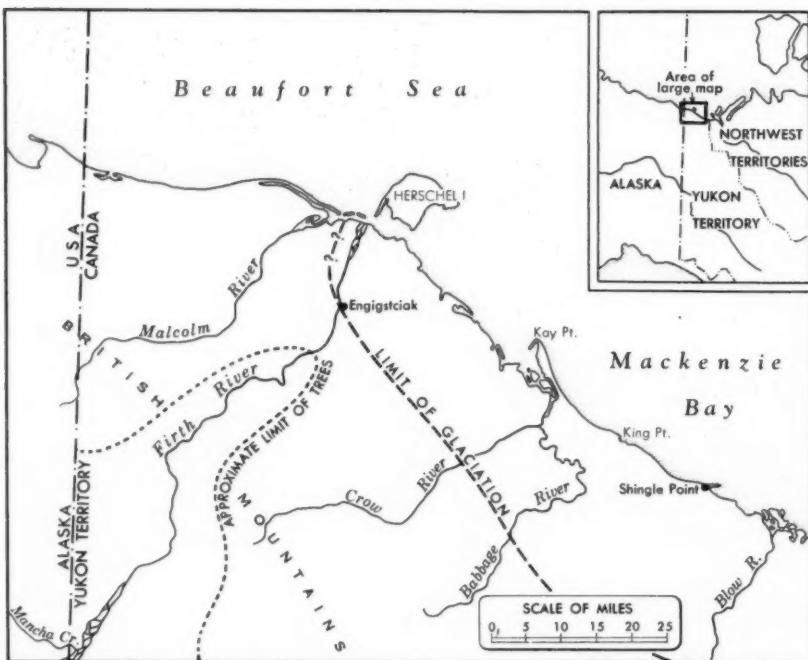


Fig. 1. Location map. Limit of glaciation mainly after Bostock (1948).

of the terraces of the Firth River. Roughly 1 mile southwest of the lookout Firth River leaves a steep-walled canyon cut for miles into the rocky floor of the valley and enters a wide flood plain marked by a network of braided channels and gravel bars. To the prehistoric inhabitants of this region Engigstciak, it seems, presented a particular appeal; the summit offered an unsurpassed view of the tundra to the hunter in his search for the larger game animals on which he depended for food; the canyon of Firth River diverted these animals in their east-west migrations to within hunting range of the locality; the plateau nearby provided campsites better drained than

the ground to the south, east, or north; Firth River at times yielded fish for food; and driftwood, carried from the forested banks of upper Firth River, was available for fuel. Investigations show that though climatic and ecological conditions have varied, this site has proved favourable for occupation by nomadic hunters throughout a long span of time.

The archaeological significance of this site was first recognized by MacNeish, who in company with a local Eskimo, Old Roland, discovered artifacts here in August 1954. Excavations were carried out in the summers of 1955, 1956, and part of 1958 on the crest and south slopes of the plateau west of Engigstciak. It became evident in 1955 that a large and varied cultural record was available at this site and that with some artifacts occurring under grey marine clay (MacNeish 1956) now at an altitude of 460 feet above sea-level, these might be linked to an extended geological history. To relate further the geological history to the archaeological finds, Mackay and Mathews spent 17 days at Engigstciak in August and September 1956, working with MacNeish (Mackay and Mathews 1956). In August 1957 Mackay revisited the site and spent a week there conducting field investigations.



Fig. 2. Looking north at the south face of Engigstciak. The rock cliff, centre foreground, is about 100 feet high.

Quaternary sediments

The area in the immediate vicinity of the archaeological finds (Fig. 3) is almost completely devoid of natural exposures of the Quaternary succession. The main sources of information on the sequence of layers consist of the archaeological excavations, whose sides expose more than 1000 linear feet of sections, and some 190 pits dug specifically for geological data. The

pits are spaced at intervals of 100 to 200 feet in areas relatively uniform in succession; in areas with a more complex succession or where one type of succession merges into another, pits are spaced as closely as several feet apart. The archaeological excavations and the pits are limited in depth by the permafrost table which lies from about 18 to 43 inches below the surface. However, as some excavations have been continued over four consecutive summers, thawing has permitted a few of the older pits to be deepened as much as 4 feet below the original permafrost table.

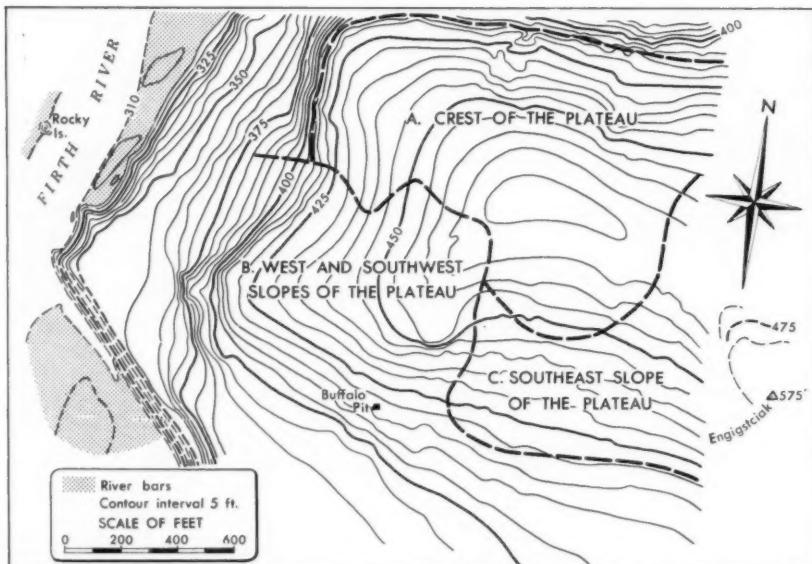


Fig. 3. Engigstciak archaeological site. The altitudes of Engigstciak (575 feet) and Firth River (310 feet) are taken from a map prepared by the Topographical Survey, Ottawa. The 5-foot contours have been mapped by both plane-table with telescopic alidade and Abney level and stadia-rod methods.

The Quaternary beds have been disturbed by the growth and melting of ground ice, intense frost heaving, solifluction, and the formation of patterned ground. As a result the sequence of layers does not everywhere represent the superposition of younger beds upon older ones; in many—and perhaps most—places overturning, repetition, and physical mixing of beds of different ages has clearly taken place. To avoid the suggestion that the sequence of beds found at the site has necessarily a stratigraphic significance, the layers are described in succession from the surface downward, rather than in the customary geological succession. Moreover, since the succession differs markedly in three more or less distinct but adjacent areas each area is considered separately (Fig. 3).

A. Crest of the plateau

Limits: A well-defined break in slope (altitude 415 feet) following a strip of shoreline gravels believed to be lacustrine, marks the northern and western limits of the area in question. The southern limit is poorly defined topographically (Fig. 3), but lies close to a line of bedrock outcrops (Fig. 4) extending northwesterly from Engigstciak. The eastern limit has not been mapped.

Surface vegetation. The tundra vegetation of this area consists of abundant grasses and sedges, 12 to 15 inches high, low shrubby willows, generally spaced at intervals of less than 3 feet, dominating in height though not in areal extent over other plants, with smaller amounts of avens (*Dryas*), prostrate willows (*Salix reticulata*), lupins, etc. and mosses in depressions. Hummocks 2 to 3 feet across and 2 to 18 inches high, with bounding vegetation-filled depressions, are general. A few poorly developed tundra (ice-wedge) polygons, 25 to 75 feet in diameter, are present.

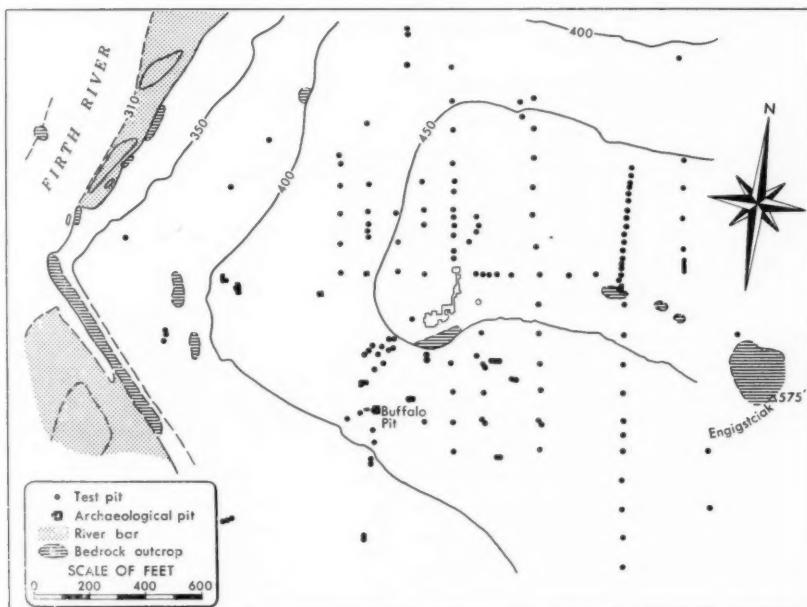


Fig. 4. Map showing test pits, archaeological pits (excavations), and bedrock outcrops.

Turf. The turf consists of a brownish grey (colour terminology follows that in the Munsell colour chart) sand to silty sand loosely bonded by living, dead, and partly decomposed plant roots. It either grades into, or is sharply separated from the underlying clay, depending on whether it is on

the top or side of the hummocks. The thickness of the horizon shows a relationship to the ill-defined pattern of hummock cracks on the ground surface, extending to greatest depth—in excess of 7 inches—below the cracks and being thin or absent in the hummock centres where locally the clay is present at the surface in frost boils.

Olive-grey marine clay. An olive-grey, slightly calcareous and somewhat stony marine "clay" from 13 to 34 inches thick underlies the much sandier turf (Table 1, specimens 1, 4, 5). Mechanical analyses show it to contain nearly equal amounts of clay-size, silt-size, and sand-plus-pebble fractions. The stones present in this sediment include red granitic and gneissic pebbles, and boulders typical of glacial detritus from the Canadian Shield, although possibly nine-tenths of the stones are of local origin. The clay has a distinctly granular structure. Its colour tends to become somewhat yellowish-green with depth. Three samples from different levels and different localities have been examined for microfossils. All have yielded some remains (Table 2, specimens 2, 3, 4). The species are known from late Pleistocene formations and from the waters off the Yukon coast at depths of from 18 to 20 fathoms. No freshwater forms were found. Additional information helpful in the separation of marine and freshwater glacial clays, is given in Appendix 1 on soil-mechanics tests.

Buried organic layer. A dark organic layer varying from humus-rich silt or clay to well-decomposed clayey or silty muck generally underlies the olive-grey marine clay, and usually is underlain in turn by a yellow-green clay. Locally, grey sand has been found in association with the organic layer, but elsewhere this sand is lacking. The organic layer, though of very great horizontal extent on the upper part of the plateau, is interrupted in many places by plugs of yellow-green clay, apparently intruded from below as a result of frost action.

As a rule the organic material rests directly on the yellow-green clay, but locally it overlies sand or frost-shattered bedrock. The basal contact is commonly so clearly defined that the layers may be separated with a knife. No traces of a root system or buried soil profile are observed in the underlying sediment. In general, the organic layer is located close to the permafrost table, lying rarely more than a few inches above permafrost and commonly immediately above it or even extending into it.

The upper limit of the organic layer is streaky, disturbed by frost action, and generally ill-defined. Organic material occurring in the turf may extend downward in the vicinity of hummock boundaries as a continuous curtain to join the organic layer (Fig. 5). Because of the uncertain upper limit of this layer its thickness is hard to establish, but a somewhat arbitrary average figure is 3.5 inches and the maximum recorded is 7 inches.

The organic layer has yielded pollen, numerous animal bones, and bone fragments, particles of wood, charcoal, sphagnum moss (some in a remarkably fresh state), and crude artifacts of the British Mountains complex (MacNeish 1956). The pollen from this layer includes white and

black spruce (19 grains), alder (19), birch (including some *Betula papyrifera*) (17), willow (9), and pine (jack or lodgepole) (4), together with smaller amounts of non-arboreal forms (23). This assemblage indicates a warmer climate than the present, judging from comparisons with pollen from higher horizons at this site, as well as from pollen spectra of lake deposits of northern Alaska (Livingstone 1955, 1957). The wood fragments appear to be made up in large part of spruce and willow roots, or branches or both. A C-14 (University of Michigan) date on one of the wood fragments (willow) was 1,560 years B.P.

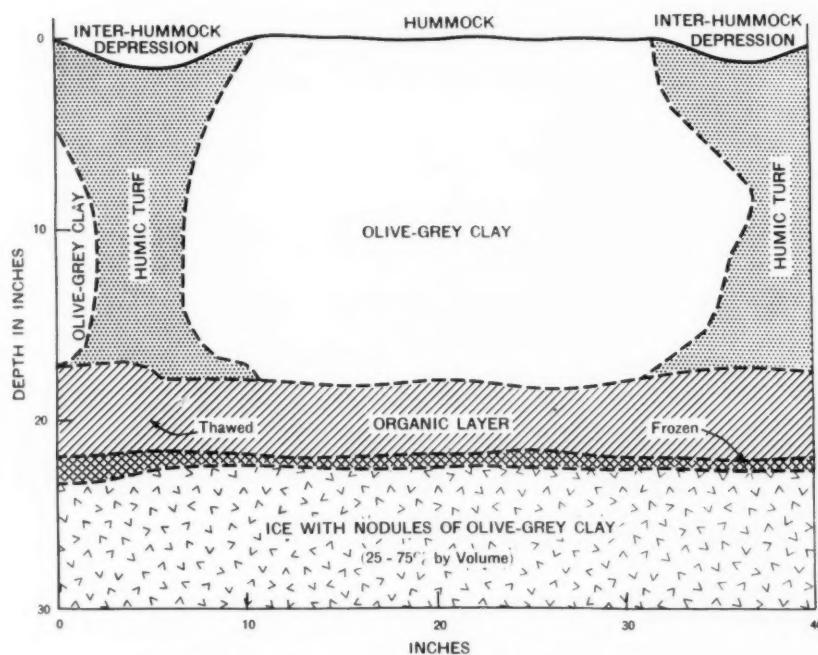


Fig. 5. Section through a hummock on the crest of the plateau showing the humic turf (under inter-hummock depressions) extending as a continuous curtain from the surface to the organic layer. Note the ground ice below the organic layer.

Yellow-green marine clay. The deepest of the Quaternary sediments exposed in this area consists of a slightly calcareous, stiff, dusky yellow-green, somewhat stony clay. A maximum of 10 inches of this material has been observed between the overlying organic layer and the permafrost table. Several excavations were made in the yellow-green clay to a depth of a foot below the permafrost table, but nowhere has the base been seen. The sediment, which consists of about equal parts of clay, silt, and sand-plus-gravel fractions (Table 1, specimens 6, 7, 8) is characterized by locally

derived rocks and by scattered pebbles of reddish granitic and gneissic rocks typical of glacial detritus originating in the Canadian Shield. No structure is evident in the clay other than numerous small ice segregations in the form of lenses, pellets, veins, and stringers in the frozen ground. The clay remains plastic enough to be kneaded by hand even though its temperature is below 0°C. and ice segregations are present. Microscopic examination (Table 2, specimens 6, 7, 8) shows marine foraminifera in one sample of the yellow-green clay and no fossils in the others. These foraminifera are known from late Pleistocene deposits in this region and are still living off the Yukon coast in depths of from 10 to 112 fathoms. No freshwater forms have been found.

Table 1. Analyses of soil samples.

Location	Specimen number	Plasticity			Grain size in per cent			Activity value
		Liquid limit	Plastic limit	Plasticity index	Clay less than 0.002 mm.	Silt 0.002-0.060 mm.	Sand more than 0.060 mm.	
Crest of plateau	1	34.7	20.7	14.0	38	42	20	0.37
	4	26.7	21.4	5.3	20	30	50	0.26
	5	—	—	—	20	33	47	—
	6	49.5	41.1	8.4	26	56	18	0.32
	7	37.5	28.3	9.2	30	33	34	0.31
	8	32.1	17.6	14.5	36	40	24	0.40
South- west slope	9	—	—	—	19	25	56	—
	10	22.3	15.4	6.9	18	32	50	0.38
	11	36.7	18.3	18.4	32	34	34	0.57
	12	—	—	—	4	13	20% gravel 63% sand	—
Miscel- laneous	14	32.7	22.3	10.4	23	25	42	0.45
	15	35.4	26.3	9.1	20	25	42	0.45
	16	45.7	32.5	13.2	32	44	24	0.41

The yellow-green clay has been distinguished from the younger olive-grey clay not only on the basis of its position under the organic layer but also, when freshly excavated, on the basis of colour, lack of granular structure, a greater stiffness in samples with natural water content and generally a greater number of stones. Mechanical analyses show it to have usually a higher proportion of clay than the shallower deposit. The differences between the two clays were however much less apparent when sections excavated in 1956 had been exposed to a year's weathering and were re-examined in 1957. Mechanical analyses (Table 1, specimens 1, 4,

5, 6, 7, 8) indicate an overlapping of many properties of the two clays. It is highly probable that colour, structure, and stiffness are secondary features developed by pedological processes and determined in large part by depth below the ground surface or above the permafrost table. Thus an isolated mass of clay moved by frost action, solifluction, or other means from its original position cannot with full assurance be correlated with either clay.

Table 2. Distribution of fossils.

	Crest of plateau				Southwest slope						
	Olive-grey clay		Yellow-green clay		Olive-grey clay		Miscel- laneous				
	2	3	4	6	7	8	11	12	13	14	15
<i>Fossils</i>											
Foraminifera:											
<i>Elphidium bartletti</i> Cushman							X				
<i>Elphidium</i> cf. <i>bartletti</i> Cushman							X				
<i>Elphidium clavatum</i> Cushman											
<i>Elphidium</i> cf. <i>clavatum</i> Cushman	X	X									
<i>Elphidium frigidum</i> Cushman							X				
<i>Elphidium orbiculare</i> (Brady)	X	X	X				X	X	X	X	
<i>Elphidium</i> cf. <i>subarcticum</i> Cushman	X										
<i>Elphidiella groenlandica</i> (Cushman)	X						X			X	
<i>Buccella frigida</i> (Cushman)							X				
<i>Cassidulina norcrossi</i> Cushman	X									X	
<i>Cassidulina teretis</i> Tappan	X	X								X	
<i>Cassidulina islandica</i> Norvang								X			
Mollusca: (fragments)							none	none			
Ostracoda:											
?juvenile of <i>Cytheridea punctillata</i>											
Brady					X						
? <i>Cytherura gibba</i> (Müller)								X			
<i>Cythereis</i> sp.									X		

B. West and southwest slopes of the plateau

Limits. This region abuts on the northeast against the area already discussed and extends south down-slope to the level of a terrace (altitude 395 feet), which is mantled with sandy alluvium devoid of archaeological remains. The eastern limit is marked by a change in microtopography and in vegetation (Fig. 3).

Surface vegetation. Avens (*Dryas*) dominates in this area, reflecting the rather well-drained sandy soil. Shrubby willows are present but notably less abundant than in the area previously described. Prostrate willows (*Salix reticulata*), bearberry, and mosses are common in depressions and lichens occur locally. Hummocks 12 to 18 inches across and a few inches high are present in the southern part of this area but are less well developed on the lower slopes.

Turf and humic sands. In most of the area the brownish sand, evidently coloured by incorporation of decomposed organic matter or humus, has a

thickness of 4 to 36 inches. The upper turf part is rather darker than the rest and richer in plant roots. However, the vertical changes in colour and abundance of rootlets are very gradual and no satisfactory boundary between the turf and the underlying 'humic sands' has been established. Usually the lower limit of the humic sands is clearly marked by a sharp, though undulating to irregular contact, either with an olive-grey sand devoid of humic streaks or with an olive-grey clay. In the humic sands a streaky colour banding, from horizontal to highly contorted, is evident in some places. Layers or lenses of olive-grey sand are common at depth in some localities. Elsewhere the colour is fairly uniform. Nearly all the humic sands and the turf horizons are fine-grained and free from stones. However, for approximately 100 feet down-slope from one of the bedrock outcrops, chips of weathered shale are found throughout the upper parts of the sand. Bone fragments, charcoal, and artifacts are common. Among the bones are those of caribou, musk ox, sheep, fox, grizzly bear, moose, rodents, fish, birds, and sea mammals in the upper part; caribou, modern bison, wapiti, mountain sheep, goat, small mammals, fish, birds, and seal are represented in the lower part.

A caribou antler from this horizon has been dated (University of Pennsylvania, P. 228), as 3250 B.P. However it is felt (Rainey and Ralph 1959) that "antler dates are erroneously young and that the discrepancy increases with age." Given a 25 per cent error, indicated by other work, this material may be as much as 4000 years old.

The humic stain may have been formed partly by the progressive burial of the organic material in cracks between hummocks, by a turf soil horizon related to the present surface, and by aeolian deposition of sand on a turf similar to the one now covering the surface. Significantly, the thickness of the humic zone is greater under the vegetation hummocks than under the cracks bounding the hummocks (Fig. 6).

Olive-grey sand. Olive-grey sand is present not only as streaks and discontinuous lenses within the humic sands, but also as a relatively thick and pure layer underlying the humic sands. As much as 14 inches of clean grey sand has been observed in several of the pits, particularly on the lower part of the south slope. In most places the lower limit of the sand was not reached because of permafrost. In a few pits the sand is underlain by clay and in one by gravel and clay.

Clay lenses. In many places on the higher slopes lenses of olive-grey clay occur either wholly within the olive-grey sand or at its upper contact. Rarely do these lenses exceed 2 inches in thickness, and commonly they are only a few feet long. They are found in many places in anticlinal folds, with axial planes coinciding with cracks between hummocks (Fig. 6). It is evident that the clay together with associated olive-grey sands and the overlying humic sands have been affected by frost movements.

The correlation of the olive-grey clay in this succession with one of the two clays in the succession on the crest and north slopes of the plateau

is at once suggested. However, colour and structure, as has been noted, are regarded as unreliable criteria. The marine fauna of the grey clay (Table 2, specimens 12 and 13) suggests a correlation with the upper (olive-grey) clay if the two are stratigraphically distinct.



Fig. 6. Contorted beds, showing anticlines and synclines, on the southwest side of the plateau: a) brownish sand below a silty turf; b) olive-grey sand; c) injected plug of olive-grey clay; d) dark brown and grey streaked silty sand. Below the trowel is a 1-to 5-inch organic layer resting on stonefree olive-grey sand, then ground ice at a depth of about 32 inches (August 19) below the surface.

Organic layer. A discontinuous organic layer, occurring under humic and olive-grey sands on the upper southwest slope of the plateau, is of considerable importance from an archaeological standpoint. It lies close to or immediately above the permafrost table, but is locally seen to be underlain by more olive-grey sand, or by yellow-green clay, and in two places by bedrock. The layer, though made up principally of decomposed organic matter, now a blackish muck, also contains some plant fragments so fresh, for example, that some willow leaves are still greenish and sphagnum moss is yellowish green. Pollen obtained from this layer is richer in tree species — spruce (34 grains), alder (20), birch (14), willow (9), pine (3), and non-arboreal (51) — than that from any of the higher horizons. The layer also contains primitive artifacts of the British Mountains complex (MacNeish 1956). Vertebrate remains include bones of a large bison, caribou, and a jaw, probably of a horse.

A correlation with the organic layer of the crest and north slope is suggested by similarities in depth and in its organic and archaeological contents.

Structural disturbances. As already indicated, contacts and colour bands in the succession are notably disturbed. On gentle slopes folds (Fig. 6) are conspicuous, with synclines containing abnormally great thicknesses of humic sand lying under the hummock centres. On slopes of from 5° to 7° the same folds are evident, but are overturned down slope (Fig. 7). On slopes of 7° to 9° some sliding has occurred on the overturned limbs of anticlines, and thrust faults are locally in evidence. In one vertical section what is believed to be a single bed of olive-grey clay has been broken and repeated by thrusting four times. Such disturbances appear to be largely confined to the uppermost 20 inches of the soil, because the organic layer close to the permafrost table lacks significant folding or faulting. It is clear from the superficial character of the folds in relationship to hummocks and to angle of slope, that they are a product of secondary soil movements and are not original structures. The total distance any particle has moved since original deposition is undeterminable, but the crumpling is sufficiently extensive so that displacements of many feet, or scores of feet, seem probable. The discontinuities and duplications in such horizons as the olive-grey clay are evidently a reflection of non-uniform displacements and thrust faulting, as are the solifluction lobes, so apparent on the lower slopes. It is surprising indeed that any general succession of beds is recognizable.

Local succession at the "Buffalo Pit". A variant of the succession described above is found on the lower southern slope of the plateau where one of the more important archaeological finds was made. Here, in the "Buffalo Pit", (altitude 410 to 420 feet), dug into the toe of a solifluction lobe, the turf is about 6 inches thick. Below this is a layer of humic sand, 3.5 to 27 inches thick, slightly contorted, showing with increasing depth a distinct banding resulting from the alternation of dark humus-rich and pale organic-poor sands. The lower part of these humic sands contains Arctic Small Tool artifacts (New Mountain culture, MacNeish 1956) as well as bones, including caribou, sheep, rodents, and the remains of one wapiti. This zone grades downward into a streaky pale brown sand from 9 to 19 inches thick, showing pronounced contortions. This in turn rests with a sharp contact on a homogeneous yellowish sand from 12 inches to at least 36 inches thick. The streaky brown sand and the yellowish sand, near their contact, contain artifacts (Flint Creek culture, MacNeish 1956) associated mainly with a large buffalo (either *Bison bison athabasci*, with premolars like those of extinct forms, or a related subspecies), a few caribou and bird bones, and with pollen indicative of a cool or cold period. In two profiles the yellowish sand was found to overlie at least 30 inches of olive-grey sand comparable to the sand exposed on the higher slopes.

In a pit immediately adjacent to the solifluction lobe on the west both the streaky pale brown sand and the homogeneous yellowish sand are

absent, and the upper limit of the olive-grey sand lies at an altitude concordant with that in the Buffalo Pit. The solifluction lobe thus appears to have developed by accumulation of what are now the pale brown and yellowish sands on a regular surface underlain by the olive-grey sand. The thickness of combined turf and humic sands is comparable both on and off the lobe, and assuming these two layers to be the combined product of weathering and of accumulation of wind-blown sand and vegetation, the solifluction lobe must have formed at an early stage of soil development and has been relatively stable since then. This early date of origin is also indicated by the lack of any weathering profile below the yellowish sands of the lobe.



Fig. 7. Overturned and disturbed beds on the southwest side of the plateau. The surface slopes about 4° to the right. a) greyish-white calcareous silt (specimen 9), which typically occurs under inter-hummock depressions; b) brownish sands with dark brown to black humic lenses, in places overturned in the down-slope direction. Under the yardstick, of which 3 inches lie outside the photograph, is a 1- to 3-inch mucky organic layer over ground ice, which lay (August 19) at a depth of about 26 inches below the surface. The ground ice had veinlets of sand 0.25 to 0.50 inches thick, dipping steeply to the west.

A layer of olive-grey clay fully 2 feet thick has been exposed under olive-grey sand in a pit west of the solifluction lobe, but was not reached in the excavations of the Buffalo Pit itself, although small pods of sandy clay were encountered at a depth of 34 to 36 inches. This clay was found to contain marine microfossils (Table 2, specimen 11). Since 2 of these species are also found in the yellow-green clay and 3 in the olive-grey clay of the crest and higher slopes, and only 2 are confined to this sample, a

correlation with either clay layer, if they are distinct, is reasonable. The distribution and extent of the clay at this spot is, however, problematical.

C. Southeast slope of the plateau

Vegetation and microtopography. Most of the southeast slope is characterized by shrubby willows 2 to 6 feet apart, prostrate willows (*Salix reticulata*), bearberry, blueberry, grasses, and sedges 12 to 15 inches high, lupins, mosses, etc. Tundra polygons, up to 100 feet across and characterized by bounding depressions a few feet wide and several inches to 2 feet deep, are well developed (Fig. 8). The depressions, which are frequently occupied by standing water, are notable for their willows, mosses, and sedges. Bare mud boils, elongated down slope, are present. Down-slope stripes are also conspicuous. The average inclination of the slope is 3° to 5° .

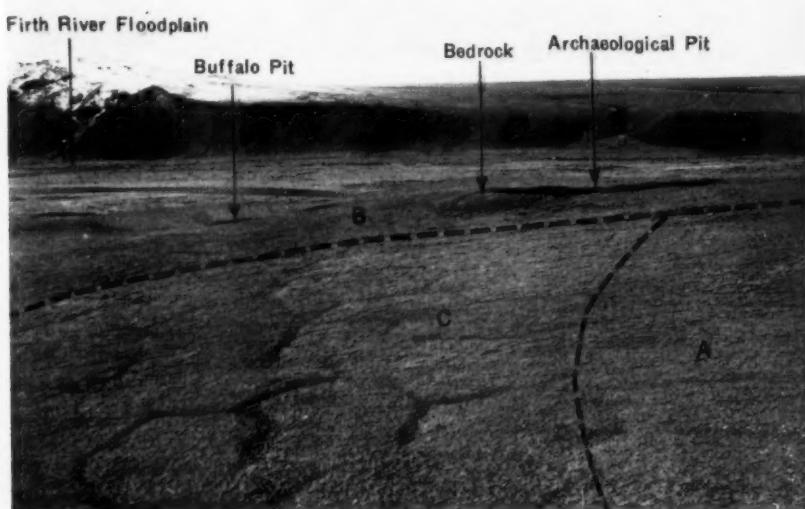


Fig. 8. View taken from the top of Engigstciak looking across the plateau to the hills on the west side of Firth River. Regions A, B, and C refer to those of the text and Fig. 3. Note the well-developed tundra polygons in region C.

The lower slope, below about the 425-foot contour, has fewer willows, but a dominant cover of avens (*Dryas*), with some prostrate willows (*Salix reticulata*), bearberry, and mosses. Tundra polygons are smaller and less well developed or absent. In some places tussocks are abundant.

Soils. Olive-grey clay, continuous with that of the crest of the plateau, rests on and has apparently overridden olive-grey and humic sands, like those to the west. This clay extends from 300 to 600 feet down from the crest

of the slope. Lower down on the slope humic or olive-grey sands or both are present at the surface. Layers rich in organic matter occur at various depths in many pits, but one, at or immediately above the permafrost table, is evidently the equivalent of the organic layer of the crest and north slope of the plateau. The turf horizon varies with the vegetation and nature of the underlying soil.

D. Relationships among the three areas

The marked contrast between the clay succession of both the crest and north slope of the plateau and the sand succession of the western and southern slopes was the subject of careful investigation. Numerous pits dug along the contact showed interfingering relationships of many of the layers, and olive-grey and humic sands overridden by olive-grey clay on the southeast slope. The complex folding — and faulting on steep slopes — of clay and sand of the southwest slopes provided at least locally an explanation of the interfingering relationships. Even though the lateral extent of a single pit may have been insufficient to show faulting and folding it is likely that this mechanism is widespread and a major factor in accounting for the observed relationships. Certainly, original interfingering of a quiet-water marine clay up-slope with a contemporaneous littoral or aeolian sand down-slope is not possible unless tilting of the land surface is assumed to a far greater extent than is reasonable with any known postglacial tectonic movements or with growth of ground ice. Even the organic layer at or immediately above the permafrost table, which at first seemed to be a reliable stratigraphic horizon suitable for correlating the two distinct successions, proved to be discontinuous, and with two distinct hypotheses regarding its mode of origin (discussed later) its stratigraphic value is seriously in doubt.

E. Ground ice

Ground ice, with only minor amounts of included foreign matter, is frequently encountered in pits that are dug a few inches below the permafrost surface (Fig. 5), especially in areas of cohesive soils, such as sandy to silty clays. Although ground ice may originate in a variety of ways and occur in different shapes and places, probably most of the nearly pure ground ice in the Engigstciak area has grown *in situ* either as ice-wedges below the fissures of tundra (ice-wedge) polygons (Fig. 8) or as tabular ice-sheets whose upper surfaces are generally parallel to the base of the active layer and lie slightly below it. As Fig. 8 shows, in some areas, principally on the southeast slope and crest of the plateau, tundra polygons with prominent fissures are numerous. The fissures are spaced from about 50 to 100 feet apart and, judging from fissures of similar size along the nearby coast where ice-wedges have been measured, those of the Engigstciak area are probably more than 2 feet in width where they flare out near the permafrost surface. Many of the wedges probably measure 5 to 10 feet across. At a conservative estimate, therefore, ice-wedges probably occupy

at least 5 per cent of the upper part of the permafrost zone. In addition, tabular ice-sheets may be present. Such ice-sheets are frequently exposed along the arctic coast, where individual sheets range from a few inches to tens of feet in thickness. One example of the occurrence of ground ice may be given for one of the larger archaeological excavations near the crest of the plateau. Below the turf there was about 10 inches of granular olive-grey clay, then 4 inches of humic sand over a 4-inch organic layer, then 2 inches of olive-grey sand and then frozen sand at a depth of 21 inches below the surface, the date of excavation being August 23, when thawing would be near its maximum extent. An area measuring 10 feet square was cleared to ground ice and a pit dug 24 inches into the ice without penetrating it. Inasmuch as ground ice is frequently encountered in pits dug in areas without fissures, and ground ice occurs below fissures, the cumulative effect of the growth of ground ice on the microrelief must be appreciable and therefore leads to considerable disturbance of the covering strata.

The stratigraphic hypothesis

In the early stages of the field work the two sequences of layers described above were regarded as stratigraphic successions complicated by a rapid facies change and later disturbed by frost heaving and solifluction. On the basis of this assumption, the following Quaternary history could be inferred.

- (1) Marine submergence to at least the present 530-foot level (and fully 60 feet above the highest point on the plateau, as shown by foraminifera present in the glacio-marine clays) accompanied by deposition of the yellow-green glacio-marine clays. This submergence presumably coincided with an advance of Pleistocene ice into Mackenzie Bay and westward to the vicinity of the site. Such ice would supply the granite and gneissic stones in the clays. Isostatic sinking of the land would have accompanied the ice advance, hence the submergence. The climate would have been either cold or moist to promote the ice advance. Human occupation of the site would have been precluded by the submergence.
- (2) Emergence, coinciding presumably with retreat of the ice sheet and accompanying isostatic uplift. Land, at least down to the 415-foot level, would have been exposed and available for establishment of a land vegetation, now recorded in the organic layer, and for human occupation. The climate, judging from pollen incorporated in the organic layer, was warmer than at present. However, as there is an apparent lack of any soil profile development in the clays below the organic layer, the period of emergence was probably brief. Some littoral and aeolian sands may have accumulated at this stage on the southwest slope of the plateau.
- (3) A second submergence to an altitude of at least 680 feet (i.e. fully 110 feet above the highest point of the plateau) leading to the deposition

of additional littoral sands on the southwest slope and then at its climax to that of the olive-grey clays, notably on the crest and north slope. This submergence can again be attributed to isostatic sinking of the land with a second ice advance brought on by a cooling or moistening of the climate. Erratic stones would then be contributed to the area by glacial ice or ice-bergs. To account for the abnormal thinning of the clays down the southwestern slope, it might be suggested that this part of the site lay within the Firth River estuary where there was clearer water than on the opposite side of the plateau facing the ice-front. Less sediment might be expected to settle from this clearer water, during the period of submergence, than in the area farther to the northeast.

(4) A second and final emergence continuing until modern conditions were attained. During this stage littoral, fluviatile, and later aeolian sands would have accumulated, notably on the southwest slope, contributing to the humic sands and the turf. During this stage conditions would again have become suitable for human occupation.

According to the history thus postulated the oldest of the cultural remains, in the organic layer immediately above or partly in permafrost, would be of interglacial or interstadial age. Because of very large gaps in the records of glacial history between the mid-western states and the Yukon coast (cf. Péwé *et al.* 1953, Detterman *et al.* 1958, Hopkins 1959), it is not possible in our opinion to correlate the local records of ice advance with those of the classic area, but possibly the two advances of our stages (1) and (3) may correspond to two stages of the Wisconsin glaciation.

When in later field work a considerable volume of evidence was gathered that was not in accord with the preceding stratigraphic hypothesis, doubts were raised as to its validity. The principal objections are as follows:

1. Lack of an erosional surface below the organic layer: with the retreat of marine waters early in stage (2) of the history, waves could be expected to lap against all parts of the area, particularly on the seaward or north slope of the plateau, from the crest (altitude 475 feet) down to or below the 415-foot level. Although the tough stony clay is admittedly resistant to wave action, at least some removal of fine fractions and redistribution of coarser products as a veneer of sand or pebbles is to be expected. Yet only a few pits out of more than 50 dug on the crest and north slope showed any sand or gravel between the organic layer and the underlying clay, and other evidence suggests this sand and gravel may be a pre-glacial lacustrine shoreline deposit. Evidence of wave action during the first emergence is thus generally lacking.

2. Lack of weathering in the clay below the organic layer: although it has been suggested already that the period of emergence in stage 2 was brief, nevertheless a withdrawal of the sea in excess of 55 feet vertically from the crest of the plateau, followed by the accumulation of many inches of peaty materials—which have been compressed to form an organic

layer several inches thick — and this in turn followed by a rise in sea-level again in excess of 55 feet, should have involved sufficient time to produce some profile development in the near-surface clay. Particularly disturbing was the complete lack below the organic layer of textural, structural, and colour changes like those of modern tundra soils (Tedrow *et al.* 1958. Tedrow and Cantlon 1958).

3. Lack of erosional surface above the organic layer: with the second advance of the sea, early in stage (3), wave action would be expected to have attacked the organic layer rather than blanketing the surface, to have truncated it at least locally, and in other places to have buried it in littoral sands. To illustrate with a modern example, the present arctic coast, 15 miles north of the site, is of similar unconsolidated sands and clays, and yet it is being cut back at an estimated rate of from a few inches to a foot or more each year (cf. MacCarthy 1953). Once again no such signs of erosion were detected, nor even on the north slope any traces of beach sands; instead, the organic layer seemed to grade upward into the overlying clays and indeed to be locally continuous with the present turf of the hummock cracks (Fig. 5).

4. The freshness of some plant remains in the organic layer: with the extended history following stage (2) there should have been ample opportunity for decomposition of plant remains in the organic layer laid down at this time. The freshness of occasional greenish willow leaves and shreds of yellow-green sphagnum moss in otherwise decomposed material seemed incompatible with great age. Care was taken to determine whether such fresh plant fragments could have been introduced by burrowing animals, but the unbroken nature of the higher organic and clay layers at the site of deposition seemed to preclude such an explanation.

A corresponding problem was raised by the C-14 dates 1560 and 3208 years B.P. determined from plant fragments and the antler in the organic layer. Such dates are wholly out of keeping with correlations with any interstadial interval in the Wisconsin (cf. Hopkins 1959), let alone a pre-Wisconsin interglacial stage. Indeed it is questionable whether a submergence exceeding 55 feet, followed by deposition of roughly 2 feet of glacio-marine stony clays and this again followed by a 475-foot emergence and the simultaneous disappearance of a major ice sheet, could all be accomplished during the past 1560 years. Doubt might be cast on the C-14 dating because of contamination of the sample by young material; indeed, fresh white and elastic rootlets, probably of grass or sedge, have been found penetrating at least 12 inches into permafrost below the organic layer. These may be of living plants (cf. Dadykin 1950) although their continuity with plants on the surface could not be established. However, the amount of such modern organic contaminants necessary to produce apparent ages of 1560 and 3208 (or 4000) years from Wisconsin remains is in excess of 50 per cent (Broecker and Kulp 1956) and would be readily detectable.

The material from which the 1560 date was obtained consists of partly decomposed and discoloured willow twigs or root fragments, not in situ, and care was taken to avoid contamination by any younger material. Rechecking of the C-14 age in the Michigan isotope laboratory, moreover, did not significantly change the date. The antler from which the second date was obtained is likewise free from visible contamination.

5. Similar development of the organic layer on different substrata: at two separate localities in the archaeological excavations the organic layer was found to transgress from a substratum of clay or sand to bedrock with no significant change in thickness or character. Were this a humus layer accumulated in situ its development on bedrock should be scanty to lacking as compared with that on a sand or clay subsoil.

6. The occurrence of organic layers below an altitude of 380 feet: organic layers occur in pits dug on an upper Firth River terrace at an altitude of 360 to 380 feet. As the terrace shows channel marks and is associated with a higher stage of the Firth River in postglacial times, the organic layer cannot be a buried soil profile of an interglacial or interstadial stage.

7. The abruptness of the change in stratigraphy from the north to the southwest slope of the plateau: although an explanation has already been offered to account for the change from a predominantly glacio-marine clay on the north slope to a predominantly sandy succession on the southwest slope, the change from one to the other should be gradual. It was found, however, that the change in several places took place within a belt less than 50 feet wide, and that this belt, moreover, showed almost no relationship to the existing topography.

The difficulties outlined are collectively so overwhelming that the authors have become convinced that the stratigraphic hypothesis is untenable.

Alternative explanation of the organic layer

An organic layer lying close to the permafrost surface below a cohesive soil, such as clay, is not a peculiarity of the Engigstciak archaeological site, but, as shown by field observations and a survey of the literature, is widespread along the western arctic coast from Cape Bathurst (128°W.) to Point Barrow (157°W.). (Mackay 1958).

G. Lowther (personal communication) has found a similar buried organic layer with artifacts on permafrost in the Porcupine River area (68°22'N. 140°27'W.; 67°35'N. 138°20'W.; and 67°37'N. 139°43'W.) south of the British Mountains, far removed from any marine submergence, and Mackay has noted buried organic layers at an altitude of about 4,000 feet

in the unglaciated area of the headwaters of Blow River (66°N. 138°W.) Tedrow *et al.* (1958, p. 36) state that "the upper portion of the permanently frozen layer . . . containing considerable organic staining and pieces of organic matter" is so typical of tundra soils of the Arctic Slope of Alaska that this "organic layer" should be considered a master horizon of an idealized tundra profile. In addition, the thickness of silt or clay covering the organic layer, both at Engigstciak and in the many coastal exposures extending over a horizontal distance exceeding 100 miles and a vertical range of many hundreds of feet, is so uniform, (about 2 feet) that it is difficult to attribute such uniformity in thickness to deposition under such varied conditions during a period of submergence. It would appear, instead, that the depth of this organic layer is controlled by the thickness of the active zone and thus is a product of an essentially modern environment in which the position of the permafrost table is established under terrestrial conditions in an arctic climate. At Engigstciak, and in the Firth River area, moreover, some of the organic layer can be demonstrated to consist of surface detritus, twigs, and leaves, rather than of the decomposed remains of a concentration of roots which might have spread out over the "thermal hardpan" immediately above permafrost.

Burial of a surface organic layer by solifluction can be considered especially on the lower slopes where topographic evidence of this process is so clear (cf. Sigafoos and Hopkins 1952). Below the leading edge of a solifluction lobe the sod of the lobe itself tends to be rolled under, like a tractor track, and laid in an inverted position on the surface of the overridden substratum. An extra thick mat of organic matter could be formed in this way. The thickness of the leading edge of an active solifluction lobe is likely to be no greater than the thickness of the active layer, and the original vegetation mat initially would be buried at approximately the depth of the permafrost table. Therefore, after the original vegetation mat was buried, the permafrost table would probably rise to approximately the position of the buried mat. To this extent a solifluction hypothesis can explain some features of the organic layer. However, with continued movement of the trailing part of the solifluction lobe the organic layer could become more deeply buried, especially on an upwardly concave slope, or become partially uncovered especially near the crest of an upwardly convex slope. The organic layer formed in this way would also grade both downward and upward into mineral soil. However, the solifluction hypothesis cannot explain burial on the crest of a ridge where the organic layer of the Engigstciak site seems best developed. Thus, whereas a solifluction hypothesis has local application, it is inadequate to account for all occurrences at Engigstciak.

Continuity of the buried organic layer with the surface sod through curtains of soil rich in organic matter below the cracks separating hummocks (Fig. 5), and the coincidence of the upright or inclined axial planes of anticlinal folds in the buried humic sands with the cracks has already been mentioned. These suggest soil movements under individual hummocks

extending downward to permafrost. It may be suggested therefore that the surface vegetation mat has been gradually rolled outward and downward below the surface by frost movement, and has been deposited on top of the permafrost during the slow down-slope creep of the hummocks themselves (Mackay 1958). This hypothesis of 'progressive burial' or of 'rolling-under of the surface and of smearing it on the permafrost' bears a relationship with the mechanism occurring at the leading edge of a solifluction lobe, but is restricted to a multitude of small areal units, like honeycomb cells, only a few feet across that function at the crest of a slope as well as at its foot. As with solifluction, the organic layer becomes buried by a mass of soil with a thickness approximately equal to that of the annual depth of thaw. There seems to be no general tendency for the organic layer, once buried, to return to the surface by a convective movement, such as has been postulated by Hopkins and Sigafoos (1951, pp. 81-3) for some frost scars; instead the depth to the organic layer may be reduced only by gradual loss of soil from the surface, or increased by injection of new material from below the organic layer as a result of down-slope movements (cf. Wiggins 1951, p. 42). In all probability the organic material, once rolled under into the deeper part of the active layer remains essentially inert, being in a thawed state and capable of flowing only during a short period of each year, or perhaps only once every few years. In support of this argument is the fact that contortions in the humic sands die out downward from mid-depth of the active zone.

The precise mechanism influencing movement within the cells remains uncertain, as does the process whereby the cells first become established. However, a series of events in the evolution on, for example, the marine clay can be postulated. In the initial stages, as a vegetation mat was developing, possibly a non-sorted net (Washburn 1956) came into existence by contraction during chilling of already frozen ground or, possibly, during desiccation. Such nets are common at the present time on the bottoms of freshly drained lakes. Alternatively, frost scars, surrounded by peat rings (Hopkins and Sigafoos 1951, p. 81) may have developed. In any event, the cells and associated surface hummocks, once established, seem to have retained their identities over long periods of time. With accumulation of a relatively deep layer of organic matter in the cracks, and with only a scanty layer over the hummock centres, differential freezing and thawing would result. The raw mineral soil of the hummock centres would freeze downward more rapidly than the adjacent material rich in organic matter (cf. Benninghoff 1952) below the cracks, and the development of ice lenses would cause it to swell. With the return of summer conditions the mineral soil of the hummocks would thaw downward more rapidly than the organic material of the cracks, it would tend to spread outward by gravity and carry with it any vegetable material. Such movement within the cells would be particularly accentuated in a down-slope direction, and on a sufficiently steep slope might even lead to overriding of one cell over its next lower neighbour.

The slowness of the rolling-under movement is shown by the disposition of the archaeological remains. Artifacts, possibly ancestral to the Eskimo of the Yukon arctic coast, occur in the surface cracks. Dwarf willows, shrub birch, and rhododendron growing on the hummocks or the sides of the depressions may be tens of years if not a hundred years old. A C-14 date indicates, however, that at least some material can be completely buried within an interval of 1560 years. Tedrow and Douglas (1958) have reported C-14 dates of organic layers (which they do not consider to be buried profiles) in the Point Barrow area as ranging from 5,300 to 10,000 years B.P.

Down-slope creep of cells must also be slow. A down-slope movement of only 10 feet in a few thousand years would result in several hummocks overriding any given point on the permafrost table, far more than sufficient to deposit a continuous layer of organic matter. If the down-slope creep was much more rapid one would expect the loss of mineral soil from the crest of the slope to have led to significant shallowing of the depth of the organic layer, and the accumulation at the foot of the slope to a deeper burial. Instead the depth shows but little relationship to gross topography, although it is true that on the crest of the plateau the organic layer may lie a few inches above permafrost and on the lower slope it may be absent or inaccessible. However, in view of both the known discontinuities in the organic layer and the possibilities of a shift in the position of the permafrost table with climatic change, this argument may have little significance.

Notwithstanding the uncertainties regarding details of the mechanisms and rates of the movements suggested here, the progressive burial hypothesis seems to offer an explanation of the buried organic layer far more in keeping with the field observations than does the stratigraphic hypothesis originally considered.

Altitude of the marine clays

A puzzling feature of the marine clays is their occurrence at Engigstciak at an altitude far higher than any known marine limits either to the west or the east. For the fossiliferous marine clays to be deposited, sea-level must have stood somewhere above the present 530-foot and below the 680-foot contour. Yet there are no high level marine features observable along the Yukon coast west of Firth River. From Demarcation Point (40 miles west of Engigstciak) to Point Barrow, there is no evidence of marine submergence other than the Flaxman formation, with its ice-rafted glacial boulders (Leffingwell 1919, MacCarthy 1958) at altitudes of less than 25 feet above sea-level. To the east of the site, there is also no evidence of a major submergence. Five samples of clay from sites between Firth River - Herschel Island in the west and Shingle Point in the east at altitudes of 180 to 680 feet have yielded no marine fossils. Within a few miles of the archaeological site itself, glacial meltwater channels, leading from a succession of ice-dammed lakes, which formed between ice to the north and

the British Mountains to the south, lie below the present 300-foot contour. Similar meltwater channels occur below an altitude of 300 feet as far east as Blow River. Thus sea-level was below the 300-foot contour when the latest ice-sheet was at, or close to, its maximum extent.

Marine clays have nowhere been found to mantle these channels nor any of the fluvio-glacial deposits and raised deltas near Engigstciak. Clays are generally absent on these fluvio-glacial deposits and deltas and such clays as have been found in two small isolated patches have yielded no marine fossils (Table 2, specimens 14 and 15).

The problem of accounting for the lower marine clay is common to both the stratigraphic and the creep hypothesis. The lower marine clay might have been deposited long before the last ice-advance and so the record of submergence might be obscured. However, according to the stratigraphic hypothesis, two marine invasions are required, and it is therefore doubly difficult to explain away the lack of record of the second submergence in adjacent areas. However, an alternative ice-thrust explanation for the origin of the anomalous altitude of the marine clay may be suggested.

The capability of glacier-ice to deform sediments on an extensive scale is well known, with numerous examples being cited by Charlesworth (1957, pp. 255-62) and Flint (1957, pp. 88-91). Evidence of thrusting by glacier-ice has been found at several points along the arctic coast within the area affected by the ice lobe that occupied Mackenzie Bay (Mackay 1956). Pleistocene beds folded, faulted, and thrust into topographically high positions have been found at Nicholson Peninsula ($129^{\circ}00'W.$) (Mackay 1957), Shingle Point ($137^{\circ}27'W.$), King Point ($138^{\circ}00'W.$), Kay Point ($138^{\circ}22'W.$) and at Herschel Island ($139^{\circ}00'W.$) (Mackay 1959).

To the south, in Alberta and Saskatchewan, somewhat similar ice-thrust features have also been observed (Gravenor and Bayrock 1955, Byers 1959, Hopkins 1923, Horberg 1952, and Slater 1927). The problem of glacier-ice thrust will be discussed more fully in a later paper, but for the present, it is suggested that glacier-ice thrust may have shoved the marine clays to their present anomalously high position.

Summary

Notwithstanding the common succession of layers at the archaeological site — marine clay overlain by terrestrial organic matter with artifacts, and this by more marine clay, which extends to the surface sod — this cannot be accepted as a stratigraphic sequence representing two marine invasions, with intervening and succeeding periods of emergence. The evidence suggests rather only a single marine invasion, coincident with an advance of glacier-ice. The marine invasion, moreover, may not have reached the present altitude of the archaeological site, but instead the marine beds laid down during this invasion may have been thrust up by glacier-ice into their present position on the northeast slope and the crest of the Engigstciak

plateau. Here, as a result of movements within the surface soil brought about by freezing and thawing and by down-slope creep, organic matter and artifacts have been subsequently incorporated into the clay as a more or less distinct layer at the base of the active layer. Some marine clay has in all probability moved down the southwest slope of the plateau, where it has come to rest on a sand deposit, which originated independently. The marine clay together with surface vegetation and archaeological remains has lately been incorporated into the sand.

From these conclusions about the geological origin of the soils, it follows that all artifacts and associated organic detritus in the clay areas of the site postdate the last glaciation of this area, whatever this may correspond to in the classical Pleistocene successions of more temperate latitudes. Artifacts found in the sands of the southwestern part of the site are probably also postglacial, although there the relationship is less clear. In any event, it is also concluded that in the clay areas of the crest of the plateau the depth at which the artifacts are now found has very little significance, except that there was time and opportunity for older remains to become more deeply buried than younger ones. In the sandy areas of the south slope the evidence of disturbance is clear in the upper horizons, and a buried muck layer occurs on the higher slopes. There also inversion may have taken place and the depth of the artifacts may have little age significance. In the Buffalo Pit, however, both the gradational contact between the humic sands and the underlying streaky sands, and the sharp contact between the streaky sands and the underlying yellowish sand are relatively free from disturbance, with no signs of involutions. It appears, therefore, that the artifacts, bones, and pollen from the humic sands have not been derived from the underlying streaky and yellowish sands, and vice versa. It seems reasonable that there the artifacts, etc., from the humic sands are younger. Elsewhere at this site the archaeological complexes will have to be dated and correlated on archaeological considerations or by C-14 analyses of animal remains, mainly bones and teeth, or of charcoal, rather than of coincidentally associated plant matter.

Although the geological investigations have provided no significant help in dating the archaeological remains, the archaeological material has, on the other hand, proved invaluable in the study of the more complex soil movements, hitherto very poorly understood, which take place in this arctic environment.

Acknowledgements

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altimeters at selected helicopter landing points. Determinations and identifications were carried out by Dr. F. Wagner (Geological Survey of Canada) on marine microfossils, Dr. J. Terasmae (Geological Survey of Canada) on palynology and wood fragments, Mr. J. A. Pihlainen (National Research Council of Canada) on the Firth River soils, Dr. A. W. F. Banfield (National Museum of Canada) on caribou bones, Mr. W. Langston (National Museum of Canada) and Dr. A. W. Cameron (Redpath Museum, Montreal) on horse and other bones, and Dr. A. Skinner (American Museum of Natural History) on buffalo and other bovidae. The C-14 analyses were done for Dr. R. S. MacNeish at the University of Michigan and the University of Pennsylvania. Dr. J. G. Fyles and Mr. G. Lowther have contributed helpful suggestions on the manuscript and Dr. D. M. Hopkins has been of considerable assistance to the authors by critically reviewing the paper. Support for the study of Mackay and Mathews in 1956 was from a grant of the Banting Research Foundation provided by the Arctic Institute of North America, and that for Mackay in 1957 from the Geographical Branch, Department of Mines and Technical Surveys, Ottawa.

Appendix 1—Soil mechanics

Supporting evidence for the origins of and differences between fluvio-glacial and marine clays, which is especially important in the absence of microfossils and convincing geomorphic evidence, may be obtained from an analysis of their plasticity (liquid and plastic limits in the Atterberg system) and grain size as shown in Figs. 9 and 10. In Fig. 9, the plasticity index (i.e. difference between liquid and plastic limits) is plotted against percentage of clay. As Skempton (1953) has shown, "inactive" clays that plot below the 0.75 activity value seem to possess one or more of the following characteristics: a composition with little clay mineral, deposition in fresh water, and deposition in salt water with subsequent leaching by fresh water. The low activity value (mainly less than 0.5) of Firth River clays is in keeping with that of glacial clays and leached marine clays.

Differences between the fluvio-glacial clays and marine clays show up clearly on Casagrande's (1948) plasticity chart for soil classification in which the plasticity index is plotted against the liquid limits, Fig. 10. Specimens 1, 4, 8, 10, and 11 are olive-grey and yellow-green clays from the Engigsteiak site. They are inorganic clays and lie above the A-Line. Specimens 6 and 7 are yellowish-green clays, which lie under organic layers. Although their grain-size differs little from that of the preceding specimens, apparently a slight addition of organic colloidal matter has increased the liquid limit so that the two specimens fall in the zone typical of organic and inorganic silts and clays. Glacial rock flour typically lies below the A-line, as with specimens 15 and 16. Specimen 15 is from soil on an esker and 16 from what is believed to be non-marine clay. Specimen 14 is from the surface of a delta and so might be of rock flour, like specimens 15 and 16.

Appendix 2 — Bedrock geology

In the area a quarter of a mile square west of Engigstciak the most conspicuous rock type is smoky grey chert, occurring in beds mainly 2 to 4 inches thick and commonly separated by shaly partings. There are about 100 feet, stratigraphic thickness, of irregularly folded beds exposed in the

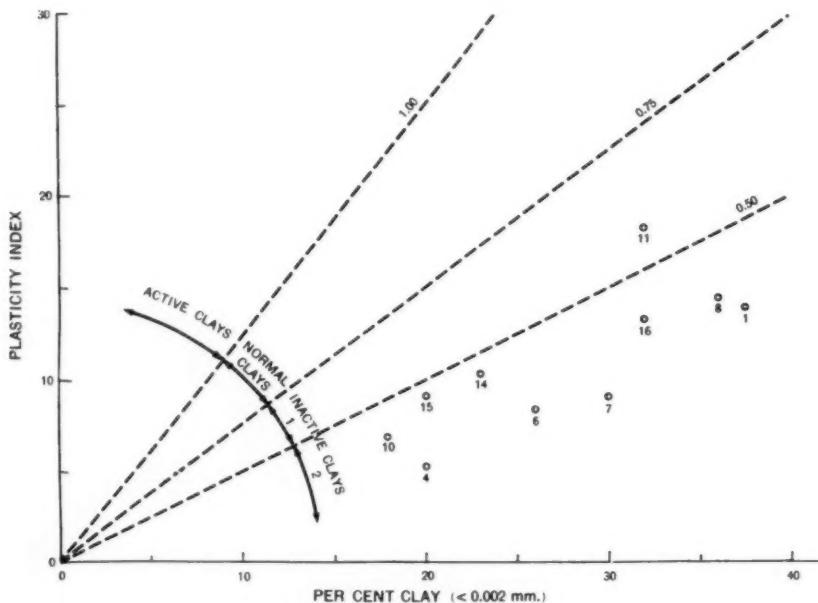


Fig. 9. Activity graph, after Skempton (1953) and Bjerrum (1954). Numbers are those of specimens referred to in Appendix 1.

core of an anticline plunging to the northwest in the southwestern part of the area, and a similar thickness in a second anticline, also plunging to the northwest, making up the rocky hill Engigstciak. The chert is flanked on the southwest along Firth River by several hundred feet of unfossiliferous black, brittle shale with minor interbedded ironstone. Although the contact with the chert is not exposed, this shale probably rests conformably on the chert. The chert is flanked on the northeast by approximately 100 feet of tightly folded pale shale, in part siliceous, that weathers to a cream colour. Although this may be an altered equivalent of the black shales, it seems more likely to be a different stratigraphic unit in fault contact with the chert. Interspersed with outcrops of the pale shale along the east bank of Firth River are two different exposures of light grey, thick-bedded, gently dipping, coarse-grained to pebbly, bioclastic limestone containing

crinoid columns, indeterminate gastropods, and sand-sized detritus of what are believed to be trepostomatous bryozoans. If the latter identification is correct and bryozoans are contemporary with the sediment, the limestone is Paleozoic. The limestone-shale contact is not exposed, but the marked discrepancy in dips suggests that the limestone rests unconformably on the highly folded shales.

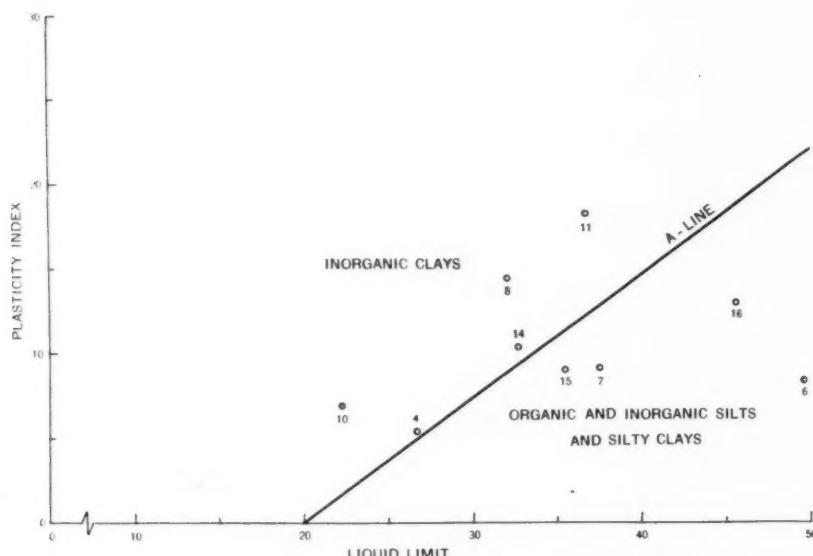


Fig. 10. Relation between the liquid limit and plasticity index after Casagrande (1948). Numbers are those of specimens referred to in Appendix 1.

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THE TRANSFER OF ARCTIC TERRITORIES FROM GREAT BRITAIN TO CANADA IN 1880, AND SOME RELATED MATTERS, AS SEEN IN OFFICIAL CORRESPONDENCE¹

Gordon W. Smith*

A. The Transfer

On June 23, 1870, the territories of the Hudson's Bay Company were formally transferred to the Dominion of Canada by Imperial order in council.² A statute of the Canadian Parliament had already made provision for the creation therefrom of the new province of Manitoba.³ Afterwards, the name Northwest Territories was generally applied to what was left of former Rupert's Land plus the old North-Western Territory, these being the lands that had been subject to the transfer. Canada's right to administer the Northwest Territories as such was not thereafter seriously in doubt, especially after the British North America Act of 1871 had been passed.⁴ What remained uncertain was the extent of the territories granted to her, since the limits of Hudson's Bay Company territory had never been conclusively settled. Equally uncertain was the status of the islands north of the mainland.

These uncertainties, and particularly the second one, were shortly to become sources of considerable concern. Two apparently innocent requests for concessions of arctic territory in 1874 — one by a British subject and the other by an American — seem to have set in motion the tangled succession of developments outlined below. These led to the transfer of all remaining British North American arctic territories to Canada in 1880, but as it turned out, this was not the end of the matter, and there followed years of doubt and confusion over the status of these northern regions.

On January 3, 1874, a Mr. A. W. Harvey, then at South Kensington, London, wrote a letter to the Under Secretary of State for the Colonies which began with the following question: "Can you inform me whether the land known as Cumberland on the West of Davis Straits belongs to Great Britain and if it does — is it under the Government of the Dominion of Canada?" He added that he would like to know because he had been carrying on fisheries there for the past two years and expected to erect some temporary buildings.⁵ On January 15 he wrote a second letter saying that he was leaving London in a short time and therefore would be glad to have the information he had asked for.⁶

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The following day Assistant Under Secretary for the Colonies Sir H. T. Holland, replying for Colonial Secretary Lord Kimberley, informed Mr. Harvey⁷ rather vaguely that a reference to the Hudson's Bay Company had revealed⁸ that the land in question had not been part of the company's territory prior to the transfer of 1869-1870, nor did it appear to have been part of Canada before Confederation. Lord Kimberley suggested that Harvey ask the Board of Admiralty whether the land had ever been taken possession of on behalf of the Crown.

About a month later, on February 10, Lt. William A. Mintzer of the U.S. Navy Corps of Engineers wrote a letter to Mr. George Crump, Acting British Consul at Philadelphia, applying through him to the British Government for a tract of land twenty miles square in Cumberland Gulf, for the purpose of carrying on a mining industry.⁹ The application was forwarded by Mr. Crump to Foreign Secretary Lord Granville,¹⁰ and passed on by his department to Lord Carnarvon, who had just taken office as Colonial Minister with the new Disraeli administration in early 1874.¹¹

The applications evidently aroused some discussion among British Government officials, as the following brief excerpts from Colonial Office files reveal. One, written to Sir H. T. Holland on April 22, ends: "If this territory does not belong to Canada as seems probable might it not be annexed with advantage to obviate possible future inconvenience".¹² Another, dated April 25, suggests:

"It would be desirable to ascertain the views of the Dominion Govt I think before the FO give any answer. We must remember that if this Yankee adventurer is informed by the British FO that the place indicated is not a portion of H.M. dominions he would no doubt think himself entitled to hoist the "Stars and Stripes" which might produce no end of complications."¹³

On April 30 Lord Carnarvon enclosed Mintzer's application in a secret dispatch to Governor General Lord Dufferin of Canada, for confidential communication to his ministers, and raised the question whether or not "the territories adjacent to those of the Dominions on the N. American Continent, which have been taken possession of in the name of this Country but not hitherto annexed to any Colony or any of them should now be formally annexed to the Dominion of Canada." Carnarvon added that the British Government would of course reserve for future consideration the course that should be taken, but would not be disposed to authorize settlement in any unoccupied British territory near Canada, unless the Canadian authorities were prepared to assume the responsibility of maintaining law and order.¹⁴

Enclosed also was a report by Hydrographer of the Admiralty Frederick Evans,¹⁵ dated April 20, which had been prepared in response to a request from the Colonial Office for information,¹⁶ particularly as to whether the territory referred to by Lt. Mintzer had ever been taken possession of on behalf of the Crown. The report gave a brief geographical and historial description of the territory in question, but admitted "Our knowledge of the geography and resources of this region is very imperfect."

Evans did note, however, that the coast some distance north of Cumberland Gulf had been visited in 1818 by Captain Ross of the British Navy, who had taken possession "in the usual form" at Agnes Monument, 70°30'N. 68°W.

On August 26 Lord Carnarvon sent another secret dispatch to Lord Dufferin containing copies of the correspondence his department had had with Mr. Harvey and saying, "I should be glad to receive an expression of the opinion of yourself and of your Ministers in regard to this application as well as on the similar one referred to in my despatch above mentioned."¹⁷ During the interval that had elapsed since his first letter was written, Mr. Harvey had moved to St. John's, Newfoundland, and had renewed his application, asking for a square mile of land for buildings and mining as well as fishing rights, but he had received a rather discouraging response. On August 25 Under Secretary for the Colonies Mr. R. G. W. Herbert had replied to him, saying that Lord Carnarvon felt obliged to consult the Governor General of Canada regarding the matter, but was not very hopeful that the desired concessions could be granted.¹⁸

On November 4 Dufferin sent a reply, also secret, to Carnarvon's dispatches of April 30 and August 26, which indicated that the latter's proposition had been favorably received by the Canadian authorities.¹⁹ Enclosed was a copy of an approved order in council, dated October 10, which stated that "the Government of Canada is desirous of including within the boundaries of the Dominion the Territories referred to, with the islands adjacent."²⁰

Several important features would appear to emerge from the correspondence thus far—the feeling in official circles in both Great Britain and Canada that there were still British territories north of the Dominion that had not yet been annexed to any colony, the willingness of the British Government to turn these territories over to Canada, the willingness of the Canadian Government to accept them, and the doubts of both governments as to what their boundaries might be.

Carnarvon's next dispatch,²¹ dated January 6, 1875, included a rather barren report by the Hydrographer of the Admiralty²² and a lengthier, more informative one done by his own department,²³ both having been submitted during the December preceding. From the evidence of the latter, he wrote:

". . . it appears that the boundaries of the Dominion towards the North, North East and North West are at present entirely undefined and that it is impossible to say what British territories on the North American Continent are not already annexed to Canada under the Order in Council of the 23rd of June 1870, which incorporated the whole of the territories of the Hudson's Bay Company, as well as the North Western territory in the Dominion."

Later in his communication he requested the advice of the Canadian ministers respecting the form of the proposed annexation, and suggested that an act of the British Parliament might be suitable. He also asked that the Canadian ministers specify the territorial limits of the lands to be annexed. This point had been discussed in his own department's minute,

which after referring to the 141st meridian separating British and American territory in the west, continued:

"To the East the British Territories might perhaps be defined to be bounded by the Atlantic Ocean, Davis Straits, Baffin Bay, Smith Sound and Kennedy Channel. But even this definition wld' exclude the extreme North West of Greenland, which is marked in some maps as British territory, from having been discovered probably by British subjects. To the North, to use the words of the Hudson's Bay Co. in 1750, the boundaries might perhaps be, 'the utmost limits of the lands towards the North Pole'."

This would appear to be the first time, in this correspondence at least, that these easterly and northerly limits were mentioned. In view of subsequent developments respecting the definition of Canada's arctic boundaries, the suggestion assumes a certain importance.

After some delay, which prompted a further letter from Lord Carnarvon on March 27 asking for a response to the above communication,²⁴ Lord Dufferin sent his reply²⁵ on May 1. Enclosed was a copy of a Canadian order in council,²⁶ which agreed that the northern boundary of Canada had never been defined and that it was impossible to say what British territory had not already been annexed to Canada. Then, after stating its approval of the boundaries proposed, the order recommended:

"To avoid all doubt it would be desirable that an Act of the Imperial Parliament should be passed defining the Boundaries East and North as follows

'Bounded on the East by the Atlantic Ocean, and passing towards the North by Davis Straits, Baffins Bay, Smiths Straits and Kennedy Channel including such portions of the North West Coast of Greenland as may belong to Great Britain by right of discovery or otherwise.

On the North by the utmost northerly limits of the continent of America including the islands appertaining thereto'."

The order in council concluded with a request that no action be taken until after the next session of the Parliament of Canada, because acquisition of the new territories would "entail a charge upon the revenue," and should therefore have the sanction of the Canadian Parliament.

Lord Carnarvon replied²⁷ on June 1, acknowledging receipt of the above and agreeing to comply with the request for delay. However, the requisite action was not taken by the Canadian Parliament during its next session, and official correspondence on the subject seems also to have lapsed until August of the following year. Canadian Minister of Justice Edward Blake, at this time in England, sent a note to Lord Carnarvon²⁸ with an extract from the New York Times enclosed, the latter announcing the organization of an expedition under Lt. Mintzer to mine graphite and mica in Cumberland Sound. The report indicated that the project was to be under the auspices of the American Government. The Colonial Office replied to Blake²⁹ on August 22, acknowledging his letter and asking if the Canadian authorities had taken or intended to take any further action in accordance with their order in council of April 30, 1875. Blake in his answer had to admit that he did not know of any action taken, nor was he

able to tell the intentions of the Canadian Government, but he would submit the matter for discussion upon his return home.³⁰

Three weeks later Lord Carnarvon sent a copy of the correspondence with Blake to Lord Dufferin, adding, "In view of the probable annexation within a short time of this and other northern territories to Canada, H. M. Govt do not propose to take any action in reference to this expedition unless expressly asked to (do) so by the Dominion Govt."³¹ A further communication from Lord Carnarvon³² enclosed an extract taken by the London Times of October 27 from the New York Times, announcing the return of Mintzer's expedition from Cumberland Sound with approximately fifteen tons of mica estimated to be worth five to twelve dollars a pound.³³

After another lengthy interval Carnarvon wrote to Dufferin on October 23, 1877,³⁴ sending him nineteen charts of the North American Arctic which had been provided by the Admiralty in response to a Canadian request of August 29 preceding. Another letter from Carnarvon, bearing the same date, appears to demonstrate the minister's growing irritation at the lack of progress in bringing the project to a conclusion.

"With reference to my Despatch, No. 297 of this day's date, I have the honor to request that you will recall the attention of your Ministers to the correspondence noted in the margin . . .

From reports which have appeared in the Newspapers I have observed that the attention of the citizens of the United States has from time to time been drawn to these territories and that private expeditions have been sent out to explore certain portions of them, and I need hardly point out to you that should it be the wish of the Canadian people that they should be included in the Dominion great difficulty in effecting this may easily arise unless steps are speedily taken to place the title of Canada to these territories upon a clear and unmistakable footing.

I have therefore to request that you will move your Ministers to again take into their consideration the question of the inclusion of these territories within the boundaries of the Dominion, and that you will state to them that I shall be glad to be informed, with as little further delay as may be possible, of the steps which they propose to take in the matter."³⁵

Dufferin's reply,³⁶ dated December 1, informed Carnarvon that he had referred the matter to his ministers, who had passed an order in council³⁷ on the subject, a copy of which was enclosed. The order in council observed that nothing had been done subsequent to the earlier one of April 30, 1875, because "there did not seem at that time any pressing necessity for taking action," and then went on to recommend that "as the reasons for coming to a definite conclusion now appear urgent" resolutions should be submitted at the next parliament authorizing the acceptance of the territories in question. No explanation was offered as to why, in the committee's view, the "reasons for coming to a definite conclusion" were so much more urgent in November 1877, than in April 1875.

A letter of February 22, 1878,³⁸ from W. R. Malcolm of the Colonial Office to the law officers of the crown, raised the question as to whether an Imperial act would be the most desirable method of making the transfer.³⁹

After noting that an Imperial act had been suggested, Mr. Malcolm continued:

"I am desired to enclose copies of opinions delivered by the Law Officers of the Crown dated respectively the 8th of November 1866 and the 8th of May 1871⁴⁰ and I am to state that as it would appear to be lawful for Her Majesty to annex territory by Letters Patent to a Colony having representative Institutions provided the assent of the Colonial Legislature is signified thereto it seems to the Secretary of State that the object in view might be effected by Letters Patent followed by Legislation in the Parliament of the Dominion without having recourse to the Imperial Parliament."

In accordance with the proposal embodied in the Canadian order in council of November 29, 1877 the transfer was brought up in the next session of parliament and the outcome was a joint address to the Queen from the Senate and House of Commons, passed on May 3, 1878.⁴¹ The resolutions were moved in the House of Commons by the Hon. David Mills, Minister of the Interior, and supported strongly by members from both sides of the House, including Prime Minister Mackenzie and Leader of the Opposition Sir John A. Macdonald. One lone member, the Hon. Peter Mitchell of Northumberland, N.B., voiced strong opposition, maintaining that the acquisition would be both expensive and useless.⁴²

The address stated in a résumé that doubts existed regarding the northern boundaries of Canada, that these doubts should be removed as soon as possible, that the British Government had offered to transfer the territories in question to Canada, that the offer had been accepted, and consequently, to remove all doubts, it was desirable that "an Act of the Parliament of the United Kingdom of Great Britain and Ireland should be passed defining the North-Easterly, Northerly, and North-Westerly Boundaries of Canada, as follows . . ." The description of the desired boundaries following this passage was essentially similar to that contained in the order in council of April 30, 1875, except that it made no direct reference to possible British territories in northwestern Greenland, and did establish a specific western boundary along the 141st meridian.

The question of whether an Imperial act was necessary to accomplish the transfer was again raised in Sir Michael Hicks-Beach's letter of July 17, 1878 to Lord Dufferin (Sir Michael having replaced Lord Carnarvon at the Colonial Office on February 4).⁴³ After acknowledging receipt of the joint address of May 3, and referring to the request for an Imperial act, Sir Michael continued:

"I have been in communication with the Law Officers of the Crown on this subject⁴⁴ and I am advised that it is competent for Her Majesty to annex all such territories to the Dominion by an Order in Council, but that if it is desired after the annexation has taken place to erect the territories thus newly annexed into Provinces and to provide that such Provinces shall be represented in the Dominion Parliament recourse must be had to an Imperial Act; since, as I am advised, the Crown is not competent to change the legislative scheme established by the British North America Act 1867 (30 and 31 Vict: c.3).

I therefore propose to defer tendering to Her Majesty any advice upon the subject of the address of the Senate and House of Commons until I am informed whether it will meet the views of your Govt that letters Patent be passed for annexing these territories to the Dominion leaving the question of Imperial legislation for future consideration if it should be thought desirable to erect any such territories not now belonging to the Dominion into Provinces."

Lord Dufferin's reply,⁴⁵ dated October 8, enclosed a memorandum prepared by Minister of Justice Rodolphe Laflamme⁴⁶ and an order in council⁴⁷ concurring in it. These documents indicate that the Hicks-Beach proposal had been received rather doubtfully by the Canadian authorities, who clearly were by no means convinced of its soundness. The main points of disagreement were set forward very ably by the Minister of Justice in his memorandum.

Briefly reviewing the circumstances leading up to the situation, he noted that the joint address of May 3, 1878, had requested an Imperial act to make the transfer, while the law officers now advised that an Imperial order in council would be sufficient. He then pointed out that a principal reason for requesting Imperial legislation had been that Lord Carnarvon himself had suggested it in his dispatch of January 6, 1875. However, apart from this, the Canadian Government still doubted that an order in council would have validity, and continued to regard an Imperial act as preferable. In their belief, the only power for extending the limits of Canada was given by section 146 of the B.N.A. Act of 1867, where specific provision was made for the annexation to Canada by order in council of Newfoundland, Prince Edward Island, British Columbia, Rupert's Land, and the Northwest Territory. The two northern territories had been duly annexed in 1870 under the terms of section 146;⁴⁸ if they in fact included the territories under discussion nothing further needed to be done, but if they did not then resort to further Imperial legislation would be advisable, since the powers given by section 146 might be exhausted in this area. For this reason, and because the boundaries of Rupert's Land and the Northwest Territory were "unknown", it had been thought better to "avoid all doubt in the matter" and obtain an Imperial act.

So far as the other issue was concerned, respecting the law officers' belief that an Imperial act would be necessary if it were desired after the transfer to create provinces from the new territories, the Canadian authorities were much less troubled. The memorandum simply drew attention to the B.N.A. Act of 1871,⁴⁹ which had granted the Canadian Parliament the right both to administer territories forming part of the Dominion but not included in any province, and to create new provinces therefrom. The minister surmised that "the attention of the Law Officer of the Crown was probably not directed to this Statute."

In spite of Hicks-Beach's lack of enthusiasm for an act of parliament to bring about the transfer, the Colonial Office proceeded to draw up a bill for this purpose, and sent a draft copy⁵⁰ of it to the Secretary of the Admiralty on January 18, 1879. The accompanying letter⁵¹ asked for any observations

the Admiralty might have on the matter, and particularly any suggestions that would help to define more accurately Canada's new boundaries. It recognized, however, that it was asking for the virtually impossible since the northern boundary was "utterly unknown", and it was "with the view of meeting this difficulty that the N. and N.E. boundaries (had been) left so vague". The key passage in the draft, which appears the more significant both because it gave open expression to official uncertainties and because the bill was never enacted into law, began as follows: "The Dominion of Canada shall include all British Territory (if any) which is not already admitted to the Union nor part of the Colony of Newfoundland and which is situate within the following boundaries . . ." The description of boundaries that followed was almost identical with that given in the Canadian joint address of May 3, 1878. Even allowing for the vagueness admitted in the letter, it is evident that this description was considerably more precise than the one that ultimately replaced it in the document finally adopted.

The reply from the Admiralty⁵² enclosed a commentary on the draft bill, with a proposed amendment, which had been prepared by Admiralty Hydrographer Frederick Evans,⁵³ and in which the Lords of The Admiralty concurred. Evans expressed doubts whether Britain should presume to claim all territory up to the northernmost extent of the archipelago, noting that British explorers had reached no further than the entrance to Smith Sound (about 78°30'N.) prior to 1852, while Americans between that date and 1873 had penetrated beyond the 82nd parallel. However, the British arctic expedition of 1875-1876 had then gone some distance beyond the most northerly point reached by the Americans. His amendment, to replace the draft bill's definition of boundaries, ran as follows:

"On the East the Atlantic Ocean, which boundary shall extend towards the North by Davis Straits, Baffin's Bay and Smith's Sound as far as the parallel of 78° 30' of North Latitude, including all the islands in and adjacent thereto, which belong to Her Majesty by right of discovery or otherwise. Thence on the North the boundary shall be the parallel of 78° 30' North Latitude, to include the entire continent to the Arctic Ocean, and also the islands in the same Westward to the one hundred and forty first Meridian West of Greenwich; and thence on that Meridian Southerly till it meets on the N. N. W. part of the continent of America the United States territory of Alaska."

Thus, if the hydrographer's statement had been adopted, no mention would have been made of the most northerly territories, and the British claim would have stopped at 78°30'N.

During the next few days there was an interesting exchange of comments among Colonial Office officials,⁵⁴ including a tartly worded suggestion from Hicks-Beach to the effect that members of his department should not propose Imperial legislation without his sanction.⁵⁵ Mr. Blake of the department expressed grave doubts about the wisdom of attempting as precise a delimitation of northern and northeastern boundaries as the hydrographer proposed, and stated his preference for leaving them indefinite.⁵⁶ This idea

was put forward still more specifically by Under Secretary Mr. Herbert in a memorandum to the minister commenting on the latter's desire to avoid a bill:

"I see the objection to legislation very clearly: on the other hand I fear that without it there will be no means of establishing the right of Canada to territories which are believed to be British but the boundaries of which have never been authoritatively defined.

If a Bill is found to be unavoidable, perhaps it might take the less assailable form of a measure 'to declare that all territories and places in North America now belonging to the Crown, but not hitherto specially included within the boundaries of the Dominion, shall be so included.' "⁵⁷

Sir Michael agreed with this suggestion, remarking that such a form would be best whether the case were dealt with by a bill or an order in council.⁵⁸

The memorandum of the preceding year by the Canadian Minister of Justice and the related documents were all sent by the Colonial Office to the Law Officers of the Crown on February 26. An enclosed letter⁵⁹, written by Mr. Herbert, drew attention to the Canadian authorities' preference for an Imperial act, and their opinion that, once the territories had been properly transferred, the B.N.A. Act of 1871 would be sufficient to permit the Dominion to create provinces therefrom. The law officers were asked to state if they believed further Imperial legislation necessary, and the letter concluded "It appears to Sir Michael Hicks Beach to be for obvious reasons undesirable to have recourse to legislation by the Imperial Parliament unless such a course is unavoidable." What the "obvious reasons" might be was not further enlarged upon.

The reply of the law officers,⁶⁰ dated April 3, confirmed their former opinion that Her Majesty could by order in council annex the territories in North America belonging to the Crown to Canada. So far as the other matter was concerned, regarding the erection of such territories into provinces, they admitted that their "attention had not been drawn" to the B.N.A. Act of 1871, and they thought that this statute would in fact give Canada full executive and legislative authority over these territories after their annexation.

The substance of the law officers' report was communicated by Hicks-Beach to the Marquis of Lorne,⁶¹ who had succeeded Lord Dufferin as Governor General in November 1878. Sir Michael added:

"I shall be prepared, therefore, should your Government desire it, to take the necessary steps forthwith for effecting the annexation to Canada of the territories in question by Means of an Order of Her Majesty in Council; — but as Imperial Legislation is not necessary for this purpose it will of course not be advisable to have recourse to it."

Evidently fearing that reservations might still be held in Canada about the proposed order in council, Sir Michael wrote a further, confidential note to the Governor General⁶² just one day later, which reveals clearly his anxiety that the change be accepted.

"Referring to my Desp. no. 106 of the 18th inst't. intimating the opinion of the Law Officers of the Crown respecting the annexation of certain territory to Canada by means of an Order in Council, I anticipate that your Gov't will share the satisfaction with which I have received this advice. There are obvious reasons which make this course of action preferable to attempting to secure the same object by the introduction of a Bill into the Imperial Parl't. Questions might be raised in the discussion of such a measure which might, in the great press of business, not improbably lead to the abandonment of the project; and I shall be glad to learn that your Gov't concur in my proposal to obtain an Order in Council for the purpose."

The Governor General's reply,⁶³ written more than 6 months later on November 5, enclosed a copy of an order in council⁶⁴ approved the day before. The order embodied a memorandum by Prime Minister Macdonald, which stated that the information about the opinion of the law officers respecting the annexation was "in the highest degree satisfactory" and requested an order in council of Her Majesty's Government for the purpose of such annexation.

On February 6, 1880 the Colonial Office sent to the law officers a draft copy of the proposed order in council,⁶⁵ requesting their opinion as to whether it would be "proper and sufficient" for its purpose. The draft was practically identical with the order as finally approved,⁶⁶ except that the effective date of the annexation, which had not yet been decided upon, was left out. It is noticeable that the description of the boundaries of the territories to be annexed abandoned earlier attempts at more precise delimitation and employed the extremely vague terminology that appeared in the final order in council. There appears to be no record of a reply from the law officers; it may be presumed, however, that their endorsement was given, in view of the above-mentioned similarity of the draft to the order as finally passed.

A draft copy of the order was sent on July 24 to Sir John A. Macdonald, who was in England at the time, with the request that he suggest an effective date for the annexation. Macdonald's reply on July 28⁶⁷ indicated that he thought the precise date immaterial, but should Lord Kimberley (the new Colonial Secretary) approve, he would suggest the first of September following. This date was immediately inserted in the draft and Lord Kimberley sent a copy on the same day to the Lord President of the Council, with the request that it be submitted to Her Majesty at the council's next meeting.⁶⁸

The order in council⁶⁹ was approved only three days later, indicating that it was handled without delay. Since it is unquestionably one of the key documents in the entire story of Canada's effort to acquire title to these northern regions, it is worth reproducing in full.

"At the Court at Osborne House, Isle of Wight,
the 31st Day of July, 1880.

Present:

The Queen's Most Excellent Majesty,
Lord President,

Lord Steward,
Lord Chamberlain.

Whereas it is expedient that all British territories and possessions in North America, and the islands adjacent to such territories and possessions which are not already included in the Dominion of Canada, should (with the exception of the Colony of Newfoundland and its dependencies) be annexed to and form part of the said Dominion.

And whereas, the Senate and Commons of Canada in Parliament assembled, have, in and by an Address, dated May 3, 1878, represented to Her Majesty 'That it is desirable that the Parliament of Canada, on the transfer of the before-mentioned territories being completed, should have authority to legislate for their future welfare and good government, and the power to make all needful rules and regulations respecting them, the same as in the case of the other territories (of the Dominion); and that the Parliament of Canada expressed its willingness to assume the duties and obligations consequent thereon.'

And whereas, Her Majesty is graciously pleased to accede to the desire expressed in and by the said Address:

Now, therefore, it is hereby ordered and declared by Her Majesty, by and with the advice of Her Most Honourable Privy Council, as follows:—

From and after September 1, 1880, all British territories and possessions in North America, not already included within the Dominion of Canada, and all islands adjacent to any of such territories or possessions, shall (with the exception of the Colony of Newfoundland and its dependencies) become and be annexed to and form part of the said Dominion of Canada; and become and be subject to the laws for the time being in force in the said Dominion, in so far as such laws may be applicable thereto.

(sgd) C. L. Peel."

Lord Kimberley sent the approved order to the Marquis of Lorne in a dispatch dated August 16,⁷⁰ and it was published in *The Canada Gazette* on October 9. Thus the formalities connected with the transfer were finally brought to a conclusion.

B. Comments

The correspondence summarized above appears to give a fairly clear picture of the rather involved negotiations leading to the transfer. However, several aspects of it merit further comment.

1. One of these is the extraordinary amount of time required to complete the transfer. The first official suggestion of a transfer was apparently made by Lord Carnarvon in his dispatch of April 30, 1874, and afterwards a sense of urgency is sometimes discernible in the remarks of officials on both sides of the Atlantic,⁷¹ yet well over six years elapsed before the order in council was finally signed on July 31, 1880. The most obvious explanation, evident from the correspondence, is undoubtedly the correct one; the British and Canadian authorities spent a good deal of time trying to determine what territories would be subject to the transfer, and then encountered more delay trying to decide whether an Imperial act or order in council should be used to effect it. Furthermore, it was a move initiated by British rather than Canadian statesmen, the Dominion Government for a considerable

time showed little interest or concern, and it fell to the lot of a few Imperial officials, principally colonial ministers Carnarvon and Hicks-Beach, to push matters along and occasionally prod the rather indifferent Canadians into action.

2. The absence of precise territorial delimitation in the order as finally constructed has aroused comment,⁷² and is certainly inconsistent with the earlier attempts to avoid leaving anything in doubt. The Colonial Office enlisted the help of the Hudson's Bay Company, the Admiralty, and the Canadian Government, as well as its own personnel, in order to determine what arctic territories were British property; and throughout most of the correspondence the quest continues for an exact definition of the territories being transferred. It is also evident in the Canadian joint address of May 3, 1878; and the remarks of the members who spoke during the debate when the address was accepted indicate their belief that a major benefit of the transfer from Canada's point of view would be the clarification of her northern boundaries. Nevertheless, all such attempts were abandoned at the end, and in the final order the British authorities resorted to the almost meaningless expression "all British territories and possessions in North America, not already included within the Dominion of Canada, and all islands adjacent to any of such territories or possessions . . . (with the exception of the Colony of Newfoundland and its dependencies) . . ."⁷³ in naming the territories subject to the transfer. Why the change?

Here again the answer or much of it seems obvious. Dr. King suggests⁷⁴ that Great Britain doubted the validity of her title to all the lands within the limits that had been proposed, and hence declined to make a precise delimitation, although she did want to transfer to Canada whatever possessions she had in this quarter. Holmden, who in general agrees with King, observes that the British did not know which of their arctic territories had not already been annexed to Canada, and that in any case an exact definition could not be given of territories that were then still largely unknown. For these reasons, he is sure, the order in council was intentionally phrased in imprecise terms.⁷⁵ All these points are borne out by the correspondence, which indicates that at the start the authorities wanted a precisely worded document, and gave up only when it became obvious that this would be impossible to achieve in satisfactory fashion. It is also clear that the Admiralty hydrographer's report of January 23, 1879, with its suggestion that the British claim stop at 78°30'N. in deference to American explorations farther north, caused second thoughts about the wisdom of an exact claim. At any rate this marks the approximate point where attempts at precise delimitation were abandoned.

Whether there were other, more obscure reasons for the change is difficult to say. The British authorities may have been genuinely reluctant to claim territories where the American title might be stronger than their own, or possibly, in more Machiavellian fashion, they may have hoped that by an indefinite claim rights could be gained, in the passage of time, that

Britain did not at the moment possess. There is the further possibility, mentioned by neither King nor Holmden, that they may not have wanted to give up all chance of a claim to part of Greenland, and so avoided precise geographical delimitation in order to keep that prospect open for the future.⁷⁶ Whatever the full explanation may be, the vagueness of the order in council as finally adopted gave rise later on to serious doubts as to what had actually been transferred to Canada.

3. Another apparent inconsistency, mentioned by King⁷⁷ and discussed at some length by Holmden,⁷⁸ is the abandonment by the Imperial authorities of an act of parliament (which they themselves had suggested in the first place) in favour of an order in council, to bring about the transfer. Again there appears to be no real mystery involved, in the light of what is revealed in the correspondence. An act was suggested by Lord Carnarvon on January 6, 1875, and during early negotiations it was assumed on both sides of the Atlantic that this device would be used. On February 22, 1878, shortly after Hicks-Beach had become Colonial Secretary, the alternative suggestion of an order in council was made at his direction, with reference to earlier opinions given by the law officers of the crown in rather similar cases, on November 8, 1866, and May 8, 1871.⁷⁹ On two later occasions (May 28, 1878 and April 3, 1879), the law officers reaffirmed that a transfer by order in council would be valid (thus removing the doubt that had bothered the Canadian authorities); whereas the Canadian Minister of Justice cited the B.N.A. Act of 1871 as evidence that Canada could create provinces from the new territories once the transfer had been completed (thus clearing up the point that had escaped the law officers themselves). In the end both sides were satisfied that the order in council was in all respects adequate, and Sir Michael, who appears to have been the chief sponsor of the change, had won his point. His motives are indicated in several of his letters, notably that of April 19, 1879, where he speaks of "obvious reasons which make this course of action preferable" and worries over the possibility that "questions might be raised in the discussion of such a measure (i.e. an act) which might, in the great press of business, not improbably lead to the abandonment of the project". There is perhaps room for a certain amount of curiosity about his "obvious reasons" and what it was he actually feared most — delay or defeat in parliament, excessive or unfavourable publicity, a strong public reaction against the project in either Great Britain or the United States — but it at least seems clear that he preferred the order in council because he thought it would be quieter, faster, and more certain of passage.

4. Another feature that seems rather odd is that the law officers could have overlooked the B.N.A. Act of 1871, since it had been passed to meet a situation rather similar to that which they were anticipating when they gave their opinion (May 28, 1878) that further Imperial legislation would be necessary after a transfer by order in council if it were desired to create provinces from the new territories. The circumstances surrounding the passing of this act are briefly as follows.

In 1870, while the Manitoba Bill was under discussion, the question was raised as to whether the Parliament of Canada had authority thus to create provinces from unorganized territories and to give them representation in the Dominion Senate and House of Commons.⁸⁰ The matter was taken under consideration, and on January 3, 1871 Governor General Lord Lisgar sent Colonial Secretary Lord Kimberley⁸¹ an approved minute of council⁸² on the subject, with an attached report, dated December 29, 1870, from the Minister of Justice (Sir John A. Macdonald). In his report Macdonald noted the difficulty that had arisen and the fact that the B.N.A. Act of 1867 did not specifically provide for the representation of the territories in the federal parliament, and then recommended that

"the Earl of Kimberley be moved to submit to the Imperial Parliament at its next Session, a Measure —

1. Confirming the Act of the Canadian Parliament 33rd Vict. chap. 3 above referred to as if it had been an imperial Statute and legalizing whatever may have been done under it, according to its true intent.

2. Empowering the Dominion Parliament from time to time to establish other Provinces in the North Western Territory . . . and also empowering it to grant such Provinces representation in the Parliament of the Dominion . . .".

A suggested draft of the requested bill was sent by Lord Kimberley to Lord Lisgar on January 26,⁸³ and a Canadian order in council was passed on February 27,⁸⁴ embodying the substance of Kimberley's draft in another that Lisgar returned to him on March 2.⁸⁵ The draft bill, in slightly changed form, was inserted in a joint address to the Queen from the Senate and House of Commons on April 13,⁸⁶ and sent by the Governor General to Kimberley on April 18.⁸⁷ The B.N.A. Act of June 29, 1871, followed.⁸⁸ The sections most relevant here read as follows:

"Whereas doubts have been entertained respecting the powers of the Parliament of Canada to establish Provinces in Territories admitted, or which may hereafter be admitted into the Dominion of Canada, and to provide for the representation of such Provinces in the said Parliament, and it is expedient to remove such doubts, and to vest such powers in the said Parliament:

Be it enacted . . .

2. The Parliament of Canada may from time to time establish new Provinces in any territories forming for the time being part of the Dominion of Canada, but not included in any Province thereof, and may, at the time of such establishment, make provision for the constitution and administration of any such Province, and for the passing of laws for the peace, order, and good government of such Province, and for its representation in the said Parliament . . .

4. The Parliament of Canada may from time to time make provision for the administration, peace, order, and good government of any territory not for the time being included in any Province."

The act also stated (section 5) that both the Rupert's Land Act and the Manitoba Act were to be deemed "valid and effectual for all purposes whatsoever".⁸⁹

Thus, if the B.N.A. Act of 1867 had failed to give Canada the power to create provinces from territories that had been or might be annexed to it, the act of 1871 would seem to have remedied this deficiency.

5. A subsequent development of interest here was the enactment of the Colonial Boundaries Act in 1895.⁹⁰ A copy of this act was sent to Canada, accompanied by a copy of a circular from Colonial Minister Joseph Chamberlain that read as follows:

"The Law Officers of the Crown having recently reported that where an Imperial Act has expressly defined the boundaries of a Colony, or has bestowed a Constitution on a Colony within certain boundaries, territory cannot be annexed to that Colony so as to be completely fused with it, as, e.g., by being included in a province or electoral division of it without statutory authority, it followed that certain annexations of territory to Colonies falling within the above category which had been effected by Order in Council and Letters Patent, accompanied by Acts of the Colonial Legislatures, were of doubtful validity, and this Act has been passed to validate these annexations, and to remove all doubts as to Her Majesty's powers in future cases."⁹¹

The act itself is very short. The main clause is given below.

"Where the boundaries of a colony have, either before or after the passing of this Act, been altered by Her Majesty the Queen by Order in Council or letters patent, the boundaries as so altered shall be, and be deemed to have been from the date of the alteration, the boundaries of the colony."

It also provided that the consent of a self-governing colony must be obtained for the alteration of its boundaries, and a schedule listed the self-governing colonies, including Canada, which were subject to this provision.

Dr. King, who does not seem to have been aware of the B.N.A. Act of 1871, takes note of the Colonial Boundaries Act, and seems to conclude that it was passed because doubts remained respecting the validity of the transfer in 1880.⁹² Holmden disagrees with this interpretation, saying that by the time the order in council of July 31, 1880 was passed, the authorities in both Great Britain and Canada were satisfied that the transfer was legal, although unquestionably there were still doubts regarding the territorial boundaries of the lands transferred in both 1870 and 1880. He believes that although the Colonial Boundaries Act would clear up any doubts about the validity of the transfer in 1880, yet it was not "intended to apply to Canada".⁹³ It seems to me that Holmden is generally correct, but nevertheless the essential point here is something rather different. That is to say, the order in council of 1880 handed over certain territories to Canada merely as territories, leaving the Dominion to administer them and erect them into provinces at her discretion under the authority of the B.N.A. Act of 1871, but the Colonial Boundaries Act was intended to deal with territories that supposedly had been, to borrow Chamberlain's phrase, "completely fused" with colonies as parts of provinces or electoral divisions, by Imperial orders in council. That being the case, the act could hardly have been designed specifically to correct flaws in the transfer of 1880.⁹⁴

6. In line with his view that it was a doubtful transfer, King says that Canada took no steps to govern or incorporate the added territory between 1880 and 1895 and implies that uncertainty as to Canadian ownership may explain the lack of action on the part of the Canadian government.⁹⁵ Again Holmden disagrees, remarking that King did not have access to all the papers connected with the transfer.⁹⁶ He refers to a correspondence between the Canadian Minister of Justice and officials of the Hudson's Bay Company, during the period from July 31, 1880 to September 23, 1882. The minister tried to obtain information about the inhabitants of the northern regions, but the Company men could give him little, and finally he recommended that no action be taken to legislate for these regions until they became sufficiently populated to make this step necessary. The minister's recommendations were embodied in the following order in council,⁹⁷ which was forwarded to the Earl of Kimberley on September 25, 1882.⁹⁸

"The Committee of Council have had under consideration a Despatch dated 16th August 1880, No. 131, from The Earl of Kimberley, enclosing an Order of Her Majesty in Council dated the 31st of July 1880, annexing to the Dominion of Canada from the 1st September 1880 such British possessions in North America (with the exception of the Colony of Newfoundland and its dependencies) as are not already included in the Dominion.

The Minister of Justice to whom the said Despatch was referred with a view to endeavour to obtain information regarding the occupants of the country North and North West of Hudsons Bay, and their habits and pursuits, reports that immediately after the reference he entered into a correspondence with the principal officer of the Hudson's Bay Company on the subject, and that gentleman very kindly caused Circulars to be addressed to such of the Agents of the Company as were likely to be able to furnish information on the points under consideration. On the 22' of July last the Chief Executive Officer of the Company, Mr. James Grahame, addressed a letter to him, the Minister, informing him that the parties to whom he had referred the enquiries were unable to furnish the required information.

The Minister is not aware of any other source where such information as is desired may be sought, and he advises that no steps be taken with the view of legislating for the good government of the country until some influx of population or other circumstance shall occur to make such provision more imperative than it would at present seem to be.

The Committee concur in the report of the Minister of Justice and advise that a copy of this Minute when approved be transmitted to Her Majesty's Secretary of State for the Colonies."

Thus Holmden's contention (contrary to King's) that Canada had accepted charge of these territories in 1880 and failed to legislate for them between that date and 1895, not because of doubts as to the validity of the transfer, but because she could find no need for any legislative or other action, would appear to be validated.⁹⁹

C. Conclusion

The documents referred to in the preceding pages appear to throw a good deal of light upon the transfer, its background, and certain other

matters related to it. Whether they leave anything of importance unsaid is a question. It is clear that Britain decided, after receiving two embarrassing and potentially troublesome applications for land and other privileges, to make Canada the proprietor of all British possessions in this area that had not already been placed under Canadian jurisdiction. There could possibly be something to Holmden's suggestion that Great Britain believed such a transfer would enable her to appeal to the Monroe Doctrine for settlement in case of a dispute with European powers.¹⁰⁰ It was an American, however, who made the original non-British application for a concession, and it is evident that the major concern of the British authorities was with the United States.¹⁰¹ They may have thought that by quietly transferring Britain's rights in this region to Canada they would be in a better position to forestall or defeat any attempt by the United States, whether based upon the Monroe Doctrine or not, to assert American sovereignty there. Furthermore, the fact of the transfer might in itself imply that the territories in question were subject to measures of sovereignty and control, both before and after the transaction was completed.

Regarding the legal status of the transfer, the total evidence of the preceding pages would certainly indicate that, although it was attended by a good deal of delay and confusion, the transfer itself was valid enough as a voluntary gift to Canada of whatever rights Britain possessed. What was in doubt, then and later, was the completeness of Britain's own title at the time of the transfer, as well as the extent of the territories subject to the transaction. Holmden puts the matter succinctly enough: "The Imperial Government did not know what they were transferring, and on the other hand the Canadian Government had no idea what they were receiving."¹⁰²

Canada's various attempts to organize and delimit the new territories began in 1895, when a Dominion order in council was passed creating the four provisional districts of Ungava, Yukon, Mackenzie, and Franklin, the last-named including the archipelago.¹⁰³ Her long effort to bring them under effective administration and control began about the same time or shortly afterwards, with the Wakeham, Low, and Bernier voyages to the Arctic, and the establishment of mounted police posts at various places on the mainland and later in the islands. However, all this is outside the scope of the present article.

¹Most of the material in this article has been drawn from documents in the Public Archives, Ottawa. Primarily these documents comprise (a) microfilm records of the Colonial Office Papers, and (b) a case labelled "Interior Dep't., Arctic Islands Documents, Reports on Sovereignty, Memoranda, Maps," which contains much of the same material, although each has some the other lacks. Most of the citations below refer to the former. In addition to the correspondence in the case, I have found extremely useful the memorandum accompanying it, which was prepared by Hensley R. Holmden, Associate Archivist in charge of the Maps Division, in 1921. In general I have tried, as much as seems appropriate, to let the documents speak for themselves. I am indebted to members of the Archives staff for much help in locating materials and otherwise facilitating the writing of the article.

²Imperial Order in Council (June 23, 1870). See in *Statutes of Canada*, 35 Vict., (1872), p. lxiii-lxxxiii.

³ *Statutes of Canada*, 33 Vict., c. 3 (Manitoba Act, May 12, 1870).

⁴ *Statutes of Great Britain*, 34-45 Vict., c. 28 (June 29, 1871). See below, at Ref. 49, 88.

⁵ *Colonial Office Papers*, Series No. 42 (henceforth cited as *C.O.42*), Vol. 734, p. 419. Harvey to Colonial Office (Jan. 3, 1874).

⁶ *Ibid.*, p. 421-2. Harvey to Colonial Office (Jan. 15, 1874).

⁷ *Ibid.*, p. 423-4. Holland to Harvey (Jan. 16, 1874). Draft copy.

⁸ *Ibid.*, p. 420. Lampsom to Holland (Jan. 12, 1874).

⁹ *Ibid.*, Vol. 732, p. 178-9. Mintzer to Crump (Feb. 10, 1874). The close relationship of the Harvey and Mintzer applications in respect to time, place, and purpose is evident, and arouses curiosity as to whether there had been any contact, friendly or otherwise, between the two men.

¹⁰ *Ibid.*, p. 177. Crump to Granville (Feb. 20, 1874).

¹¹ *Ibid.*, p. 176. Foreign Office to Colonial Office (March 28, 1874).

¹² *Ibid.*, Vol. 731, p. 51. W.D. (?) to Sir H. T. Holland (April 22, 1874). This document, and the one following, are in the Archives microfilm, but not in the case *Arctic Islands Documents* . . .

¹³ *Ibid.*, p. 52 (April 25, 1874). Signature illegible.

¹⁴ *Ibid.*, Vol. 731, p. 58-60. Carnarvon to Dufferin (April 30, 1874). Draft copy.

¹⁵ *Ibid.*, p. 55-7.

¹⁶ *Ibid.*, Vol. 732, p. 180-1. Holland to Secretary of the Admiralty (April 13, 1874). Draft copy.

¹⁷ Carnarvon to Dufferin (Aug. 26, 1874). From handwritten copy in case *Arctic Islands Documents*

¹⁸ H. R. Holmden, *Memo re the Arctic Islands* (Ottawa: Public Archives manuscript, 1921), p. 3-4. I have not been able to locate Herbert's letter in the Archives documents, but Holmden must have seen it, because he quotes from it verbatim. Nor have I seen any record of a reply to Mintzer.

¹⁹ *C.O. 42*, Vol. 730, p. 5-6. Dufferin to Carnarvon (Nov. 4, 1874).

²⁰ *Dominion Order in Council*, P.C. No. 1248 (Oct. 10, 1874).

²¹ *C.O.42*, Vol. 731, p. 196-9. Carnarvon to Dufferin (Jan. 6, 1875). Draft copy.

²² *Ibid.*, p. 189-95 (Dec. 2, 1874).

²³ *Ibid.*, p. 179-85 (Dec. 19, 1874).

²⁴ *Ibid.*, p. 200. Carnarvon to Dufferin (March 27, 1875). Draft copy.

²⁵ *Ibid.*, Vol. 736, p. 393. Dufferin to Carnarvon (May 1, 1875).

²⁶ *Dominion Order in Council*, P.C. No. 46D (April 30, 1875).

²⁷ *C.O.42*, Vol. 736, p. 396. Carnarvon to "The Officer Adm. the Govt." (June 1, 1875). Draft copy.

²⁸ *Ibid.*, Vol. 747, p. 476-7. Blake to Carnarvon (Aug. 15, 1876).

²⁹ *Ibid.*, p. 479-80. Colonial Office to Blake (Aug. 22, 1876). Draft copy.

³⁰ *Ibid.*, p. 369. Blake to Colonial Office (Aug. 23, 1876).

³¹ *Ibid.*, p. 371. Carnarvon to O.A.G. (Sept. 13, 1876). Draft copy.

³² *Ibid.*, p. 373. Carnarvon to Dufferin (Nov. 1, 1876), Dispatch No. 324. Draft copy.

³³ Holmden, *op. cit.*, p. 10, draws attention to a statement by Donald Smith (afterwards Lord Strathcona) in Canada, *House of Commons Debates* (May 3, 1878), p. 2392, to the effect that the cargo was worth \$120,000. Smith did not identify the Mintzer expedition by name, but there is little doubt it was the one to which he referred.

³⁴ Dispatch No. 297 (Oct. 23, 1877).

³⁵ Dispatch of Oct. 23, 1877. Both this document and the preceding one are reproduced in handwriting in the case *Arctic Islands Documents* . . . , but do not appear to be in the Archives microfilm.

³⁶ *C.O. 42*, Vol. 749, p. 788-9. Dufferin to Carnarvon (Dec. 1, 1877).

³⁷ *Dominion Order in Council*, P.C. No. 922D (Nov. 29, 1877).

³⁸ *C.O. 42*, Vol. 749, p. 793-5. Malcolm to attorney general and solicitor general (Feb. 22, 1878). Draft copy.

³⁹ This doubt is now raised in the correspondence for the first time, so far as I can tell.

Holmden, *op. cit.*, p. 14, is obviously in error when he asserts that it was first brought up in Hicks-Beach's letter of July 17, 1878.

⁴⁰ Below, Ref. 79.

⁴¹ C.O.42, Vol. 753, p. 391-4. See the text of the joint address also in Canada, *Senate Debates* (May 3, 1878), p. 903; and in W. F. King, *Report upon the Title of Canada to the Islands North of the Mainland of Canada* (Ottawa: Gov't. Printing Bureau, 1905, p. 9-10). King was Chief Astronomer of the Dominion.

⁴² Canada, *House of Commons Debates* (May 3, 1878), p. 2386-94. Holmden, *op. cit.*, p. 11, says that some of the official correspondence on the subject had been secretly shown to Macdonald the day before.

⁴³ C.O. 42, Vol. 753, p. 395-7. Hicks-Beach to Dufferin (July 17, 1878), Dispatch No. 184. Draft copy.

⁴⁴ See Ref. 38 above; and C.O. 42, Vol. 754, p. 531-3. Law Officers to Hicks-Beach (May 28, 1878).

⁴⁵ *Ibid.*, Vol. 754, p. 142. Dufferin to Hicks-Beach (Oct. 8, 1878). Dispatch No. 247.

⁴⁶ *Ibid.*, p. 145-51 (Aug. 30, 1878).

⁴⁷ *Ibid.*, p. 143-4. *Dominion Order in Council*, P.C. No. 1162D (Oct. 2, 1878).

⁴⁸ *Imperial Order in Council*, June 23, 1870 (above).

⁴⁹ *Statutes of Great Britain*, 34-35 Vict., c. 28 (*The British North America Act*, June 29, 1871). See sections 2 and 4 (below, at Ref. 88).

⁵⁰ C.O. 42, Vol. 754, p. 156-9.

⁵¹ *Ibid.*, p. 152-5. Colonial Office to Secretary of the Admiralty (Jan. 18, 1879). Draft copy.

⁵² *Ibid.*, Vol. 759, p. 24-5. Admiralty to Colonial Office (Jan. 28, 1879).

⁵³ *Ibid.*, p. 26-32. Hydrographer's Report (Jan. 23, 1879).

⁵⁴ *Ibid.*, p. 19-23.

⁵⁵ *Ibid.*, p. 20 (Feb. 6, 1879).

⁵⁶ *Ibid.*, p. 19 (Jan. 29, 1879).

⁵⁷ *Ibid.*, p. 22 (Feb. 10, 1879).

⁵⁸ *Ibid.*, p. 22 (Feb. 20, 1879).

⁵⁹ *Ibid.*, p. 33-9. Colonial Office to Law Officers of the Crown (Feb. 26, 1879). Draft copy.

⁶⁰ *Ibid.*, p. 195-8. Law Officers to Hicks-Beach (April 3, 1879).

⁶¹ *Ibid.*, p. 199-201. Hicks-Beach to Marquis of Lorne (April 18, 1879), Dispatch No. 106. Draft copy.

⁶² *Ibid.*, p. 202-3. Hicks-Beach to Marquis of Lorne (April 19, 1879). Draft copy.

⁶³ *Ibid.*, Vol. 758, p. 11-12. Marquis of Lorne to Hicks-Beach (Nov. 5, 1879). Dispatch No. 315.

⁶⁴ *Ibid.*, p. 13-14. *Dominion Order in Council*, P.C. No. 88E (Nov. 4, 1879).

⁶⁵ C.O. 42, Vol. 758, p. 8-10, 15. Colonial Office to Law Officers of the Crown (Feb. 6, 1880). Draft copy.

⁶⁶ Below, at Ref. 69.

⁶⁷ C.O. 42, Vol. 765. A.S. Dennis to Colonial Office (July 28, 1880). Acknowledged in *ibid.*, Colonial Office to Macdonald (July 31, 1880).

⁶⁸ Lord Kimberley to Lord President of the Council (July 28, 1880). Copies of documents cited in this and the preceding reference are in the case *Arctic Islands Documents*, but evidently not in the Archives microfilm.

⁶⁹ *Imperial Order in Council* (July 31, 1880). See in C.O. 42, Vol. 764, p. 329; also *The Canada Gazette*, Vol. XIV, No. 15 (Oct. 9, 1880), p. 389; and W. F. King, *op. cit.*, p. 10.

⁷⁰ C.O. 42, Vol. 764, p. 330. Kimberley to Marquis of Lorne (Aug. 16, 1880), Dispatch No. 131. Draft copy.

⁷¹ More evident, in the case of the Canadians, during the later stages of the negotiations. E.g., see the remarks about the need for speedy action by Mackenzie, Mills, and Macdonald in the House of Commons on May 3, 1878.

⁷² E.g., W. F. King, *op. cit.*, p. 4-8; H. R. Holmden, *op. cit.*, p. 11-13, 17ff.; A. E. Millward, *Southern Baffin Island* (Ottawa: King's Printer, 1930), p. 12-13.

⁷³ If taken at face value this would presumably include British Honduras, Bermuda, the Bahamas, and the British West Indies. So far as I know no one has ever raised the question as to whether all these possessions were inadvertently handed over to Canada at the time of the transfer!

⁷⁴ W. F. King, *op. cit.*, p. 6.

⁷⁵ Holmden, *op. cit.*, p. 11-12.

⁷⁶ See Colonial Office minute of Dec. 19, 1874 (above). In this connection it is perhaps worth recalling that the Nares expedition had been active in northwest Greenland in 1875-1876, and had explored farther along the northern coast than any other expedition up till that time. Lt. Greely of the U.S. Army did not begin his expedition to the same region until 1881.

⁷⁷ King, *op. cit.*, p. 5.

⁷⁸ Holmden, *op. cit.*, p. 14 ff.

⁷⁹ L.O., 10568/66 Cape (Nov. 8, 1866), and L.O., 4558/71 Cape (May 8, 1871). The first advised that the annexation of "Nomansland" to Natal, which had been brought about in 1863-4 by means of letters patent and a local ordinance, had been lawful, and that the proposed annexation of the Penguin Islands to Cape Colony could also be effected by the Crown. The second advised that the annexation of Chief Waterboer's territory to Cape Colony could similarly be effected by the Crown. In each of the proposed annexations, according to the law officers, Her Majesty's action should be accompanied by an act of the local legislature.

⁸⁰ Both the order in council cited below (see Ref. 82) and the attached report by Macdonald say that the question was raised "during the last Session of the Canadian Parliament". I do not see any direct reference to it in the debates, except that on May 4 Mr. Mills asked "if the Government intended to ask the Imperial confirmation of the power of this Bill", and Macdonald replied that there was "some doubt in this respect about the appointment of Senators". Mr. Wood thought that "with the exception of Senators the provisions of the Bill would be embraced under an Imperial Order in Council". *House of Commons Debates* (May 4, 1870), cols. 1361-2.

⁸¹ C.O. 42, Vol. 696, p. 2-4. Lisgar to Kimberley (Jan. 3, 1871). Dispatch No. 1.

⁸² Dominion Order in Council, P.C. No. 503 (Jan. 2, 1871). See, with Macdonald's report, in C.O. 42, Vol. 696, p. 8-13.

⁸³ C.O. 42, Vol. 696, p. 5-6. Kimberley to Lisgar (Jan. 26, 1871). Dispatch No. 341.

⁸⁴ Dominion Order in Council, P.C. No. 416B (Feb. 27, 1871).

⁸⁵ C.O. 42, Vol. 697, p. 18-19. Lisgar to Kimberley (March 2, 1871). Dispatch No. 53.

⁸⁶ Canada, *Journals of the Senate* (April 13, 1871), p. 154-5, gives the complete text. See also *House of Commons Debates* (April 13, 1871), cols. 1081-2.

⁸⁷ C.O. 42, Vol. 697, p. 516-7. Lisgar to Kimberley (April 18, 1871). Dispatch No. 86.

⁸⁸ *Statutes of Great Britain*, 34-35 Vict., c. 28 (June 29, 1871).

⁸⁹ Holmden, *op. cit.*, p. 20-2, emphasizes the differences between the Canadian draft or drafts and the final act, and says that the Imperial authorities, refusing to accept the former, composed the latter themselves. It is true that there are differences, but most of them are of minor importance, and essentially the Kimberley draft, the Canadian drafts of Feb. 27 and April 13, and the final act are similar in import if not in structure. Note also that the Kimberley draft, which Holmden does not mention, set the pattern for the Canadian drafts. Holmden did not see the joint address of April 13, nor, apparently, did he see a note from the Colonial Office to the Secretary to the Treasury (C.O. 42, Vol. 697, p. 22-4, May 2, 1871), which shows clearly that the British authorities were in fact trying to meet the wishes of the Canadian Government.

⁹⁰ *Statutes of Great Britain*, 58-59 Vict., c. 34 (July 6, 1895).

⁹¹ Chamberlain to Officer Administering the Government (July 26, 1895).

⁹² W. F. King, *op. cit.*, p. 5, 8.

⁹³ Holmden, *op. cit.*, p. 23-6. Perhaps he meant that the Imperial authorities, in passing the act, did not have Canada primarily in mind. The act must have been intended to be applicable to Canada, since Canada was one of the self-governing colonies

named in the accompanying schedule. See also A. E. Millward, *op. cit.*, p. 12.

⁹⁴ See Great Britain, *Parliamentary Debates*, 4th Series, 58-59 Vict., Vol. xxxv (June 25-July 6, 1895), Cols. 46-7, 195. Speaking in the House of Lords on July 1, the Marquess of Ripon, outgoing Secretary of State for the Colonies in the defeated Rosebery Administration, said in reference to the proposed measure: "Some small islands have been added to New Zealand; and the boundaries of some Australian colonies have been altered. The doubts relate to cases of that kind."

Three days later the following exchange took place in the House of Commons:

"Dr. Clark asked whether under this Bill Cape Colony and Natal would be able to extend their borders without reference to that House.

The Secretary of State for the Colonies (Mr. J. Chamberlain, Birmingham, W.) replied in the negative."

⁹⁵ W. F. King, *op. cit.*, p. 6, 8.

⁹⁶ Holmden, *op. cit.*, p. 23.

⁹⁷ *Dominion Order in Council*, P.C. No. 1839 (Sept. 23, 1882).

⁹⁸ C.O. 42, Vol. 772, p. 182-3. Sir W. J. Ritchie (Administrator) to Kimberley (Sept. 25, 1882). Dispatch No. 28.

⁹⁹ A. E. Millward, *op. cit.*, p. 13, interprets Lt. A. R. Gordon's three voyages in 1884, 1885, and 1886 as being connected with Canada's assumption of responsibility in the newly transferred territories. I can find little to justify this supposition, since, as Gordon's narratives and Millward's own quotations and comments make clear, the voyages were designed primarily to gather information about navigation in Hudson Strait, and they penetrated no farther north. See Gordon's three *Reports*, for 1884, 1885, and 1886, issued under the authority of the Minister of Marine and Fisheries, in the departmental annual reports.

¹⁰⁰ Holmden, *op. cit.*, p. 12-13.

¹⁰¹ See Blake of the Colonial Office to Bramston in C.O. 42, Vol. 759, p. 19 (Jan. 29, 1879): "The object in annexing these unexplored territories to Canada is, I apprehend, to prevent the United States from claiming them, and not from the likelihood of their proving of any value to Canada."

¹⁰² Holmden, *op. cit.*, p. 12. See also V. Kenneth Johnston, "Canada's Title to the Arctic Islands", *The Canadian Historical Review*, XIV, No. 1 (March 1933), p. 24-41, esp. p. 29. Johnston questions that Britain's title to all the islands was perfect by the end of the nineteenth century; nevertheless he seems to consider that the transfer as such had been valid. E.g. ". . . the British government, by order-in-council in 1880, transferred to Canada all British territories in North America except Newfoundland and its dependencies . . ." He then adds, evidently following King, that the order "was confirmed by imperial statute in 1895". Yvon Bériault, *Les Problèmes politiques du Nord canadien*, University of Ottawa doctoral thesis (Montreal: Bernard Valiquette, 1942), makes several references to the transfer (e.g., p. 100, 101, 111, 112, 113) and raises questions about it, but otherwise does not go into detail.

¹⁰³ *Dominion Order in Council*, P.C. No. 2640 (Oct. 2, 1895).

NOTES

UNIVERSITY OF ALASKA GULKANA GLACIER EXPEDITION

During the summer of 1960 glaciological investigations were initiated on Gulkana Glacier in the central Alaska Range by members of the Department of Geology, University of Alaska. The programme is being supported by a grant from the National Science Foundation awarded to Dr. Troy L. Péwé, project supervisor and head, Department of Geology.

Interior Alaska is a physiographic and climatic area heretofore almost neglected in glacier studies, in contrast to southeastern Alaska. The little work that has been done indicates that the glaciers in the interior deserve attention from the standpoint of present and historical fluctuations and studies of flow, ablation, and structure. At least two glaciers in the central Alaska Range are of special interest inasmuch as they have undergone advances as rapid, or more rapid than any others in the world. Gulkana Glacier lies on the south side of the Alaska Range 4 miles east of the Richardson Highway and about 135 miles southeast of Fairbanks. This glacier was chosen on account of its accessibility, size, structure, and because a 50-year photographic record of it is available.

The glacier is 2.5 miles long and flows essentially to the south, the average width is about 1 mile. On the western side an ice fall divides the glacier roughly in half. The lower half is composed of three ice streams. The altitude of the terminus is 3950 feet and that of the ice in the cirque areas 6500 to 7000 feet.

Paul V. Sellmann and N. W. Rutter, graduate students of the Department of Geology, University of Alaska, each led a small field party and began investigations in the second week of June 1960. The work lasted until mid-September

and was divided into two broad projects: ablation and flow studies by Sellmann and a study of structure by Rutter. A topographic map of the glacier was constructed by plane-table methods; it has a scale of 1:2000, 20-foot contour intervals and was completed by the middle of the summer. A triangulation net with altitudes was also completed in order to provide better control for flow and ablation studies. Liberal assistance was given by the U.S. Army Cold Weather and Mountain School, Fort Greely, Alaska in providing air transport for establishing base camps.

Ablations studies. To obtain information on the rate of lowering of the ice surface a total of 65 10-foot wooden stakes of 1-inch diameter were set in the glacier. They were installed with the aid of a SIPRE ice auger and all held firm. However, resetting of stakes on the lower glacier was necessary. Measurements were made at all stakes at 10-day intervals and daily measurements on a few stakes for correlation with meteorological data, which were recorded daily throughout the summer. Additional stakes were set in the glacier where ice thickness and type of morainic cover on the ice varied. It was found that the total summer lowering of the clean ice surface was 15 feet near the terminus and 17 inches in the upper parts of the glacier.

Movement. The ablation stakes were also used for movement studies. Controls were set up on the various ice streams composing the glacier. The stakes were surveyed with a theodolite at the time they were set, and again later to determine the amount of movement.

Two transverse profiles were established between the terminus and the ice falls. These will be used for an annual check of the actual level of the ice at these sections. Photographs were taken

from established photo stations that had been occupied at various times during the last 50 years by Moffett and Péwé.

Structure. The structural studies were directed mainly toward the mapping of foliation. Dips and strikes of the folia were mapped in detail with Brunton compass and fixed by bearings taken from known points. An arc pattern of foliation is displayed between the ice falls and the terminus; the dip of the folia becomes in general less steep down-glacier. In the main ice stream on the east an indistinct half-arc is present. Near the margin of the glacier, and adjacent to moraines the foliation is dense, with very steep dips.

Transverse, en echelon, splaying, and chevron crevasses were plotted with the aid of air photographs. Forbe's bands and sedimentary layers also occur and were plotted. A series of faults is present in the terminus and was mapped by plane table.

Geophysical measurements. Gravity measurements were taken along two controlled transverse sections by Rex Allen of the Branch of Geophysics, U. S. Geological Survey through the co-operation of David F. Barnes, Geophysicist. **Glacial geology.** Moraines of at least two recent advances were mapped. Lichenology was used exclusively for relative dating inasmuch as the area is above tree line. It is expected that the advances can be correlated with those in 1750 and 1850 of the Canwell, Castner, and Black Rapids glaciers to the north, where both lichen and tree-ring studies have been made.

TROY L. PÉWÉ

A STUDY OF GLACIAL GEOMORPHOLOGY IN THE NORTHERN TORNGAT MOUNTAINS, LABRADOR

This study was begun in 1959 and continued during the field season of 1960, when my wife Inger-Marie acted as assistant and we spent a little over 9 weeks in the field from early July to mid-September.

Base camp was set up at the northern end of Eclipse Channel and from there several journeys of 3- to 8-day duration

were made. North Aulatsivik Island and the area to the north toward Telliaosilk Fiord were studied. Lack of a canoe prevented the crossing of Eclipse River, and the area to the south of it could therefore not be visited.

Study of the post-glacial emergence shows a discontinuous displacement of the strand-line. Three well-developed strand-lines were found at 40 to 56, 26 to 36, and 15.5 metres above sea-level. The two higher ones slope to N. 25° E. at a gradient of 1:1000 and 1:1650 respectively for the higher and lower. Isobase-directions for these two levels are found to be approximately 115—295°, and a map with contour lines showing the former sea-levels has been prepared. The lowest strand-line shows no tilt and is regarded as horizontal.

An equal-distance diagram has been plotted and shows that a major transgression took place in northern Labrador prior to the formation of the lowest strand-line. At Port Burwell the sea-level rose some 12 metres above the level it had during the formation of the next higher strand-line.

Fossil marine molluscs were found in the base-camp area up to 32 metres above sea-level. A shell sample taken at 29 metres has been submitted for radio-carbon dating through the Geographical Branch, Department of Mines and Technical Surveys. The result will provide the first absolute date for any late- or post-glacial event on the Labrador coast.

Mr. V. Conde of the Redpath Museum, McGill University has kindly determined the molluscs and found a boreal-arctic fauna. *Mya truncata*, *Hiatella arctica*, and *Astarte borealis* are the dominant species.

Several terminal moraines were located, e.g., along Telliaosilk and Noodleook fiords, on North Aulatsivik Island, in the base-camp area, and Eclipse Valley. The study of strand-lines has made a correlation between them possible.

The maximum extent of the (last?) glaciation was studied and the upper trim-line and kame-terrace levels that have been found farther south¹ were

found also in this area. On the southern side of Telliaosilk Fiord they lay approximately 500 feet lower than at Kangalaksiorvik Lakes.

The results of the two field seasons will be worked up and presented as Ph. D. thesis at McGill University in 1961.

Financial support for the field work was provided by a grant from the Banting Fund through the Arctic Institute of North America and by the McGill-Carnegie Arctic Research Program. Air transport from Nain to the Torngat Mountains and back to Goose Bay was generously provided by the British Newfoundland Exploration Company, and I am much indebted to Dr. A. P. Bevan and Mr. Piloski for their help.

OLAV LØKEN

¹ Ives, J. D. Glacial geomorphology of the Torngat Mountains, northern Labrador. *Geo. Bull.* No. 12:47-75. 1958.

COMMENTS ON "CARNIVOROUS WALRUS AND SOME ARCTIC ZONOSES"

In this interesting paper (Arctic 13: 111-22) F. H. Fay suggests that polar bears and walrus contract trichinosis primarily from the flesh of ringed and bearded seals. I do not necessarily dispute this, but I do suggest that Fay unduly discounts other sources of infection.

Bears are omnivorous scavengers and at times will eat, or try to eat, the most unlikely substances. Armstrong¹ gives the stomach contents of a bear shot in Prince of Wales Strait as a few raisins, small pieces of pork fat, some tobacco leaves, and two pieces of common adhesive plaster. I have known them to chew into cans of engine oil. They walk long distances overland and along the shore and must frequently find carcasses of foxes, small mammals, and occasionally of other bears. That polar bears do not hesitate to eat the flesh of their own species is well known. Cases are mentioned by Edvard Bay² and by Stefansson³, and I have had caches of bear meat broken into and partly eaten by other bears. Occasionally cubs may be killed deliberately and eaten^{4,5}.

In 1958-9 the Eskimos at Resolute reported that bears were eating trapped

foxes, and during the same season five out of 25 fox diaphragms examined were infected with *Trichinella*⁶. In 1949 on Prince Charles Island we saw places where bears had turned over stones, presumably in search of lemmings. (cf. Ref. 4, p. 110). When lemmings are really abundant it would be possible for a bear to obtain considerable numbers with very little effort. In the areas where ground squirrels are common it is not unlikely that these are also sometimes eaten. In the past when Eskimos abandoned their dead or gave them a very perfunctory burial, even humans may have been a source of infection.

Fay dismisses a bear — walrus — bear cycle as altogether untenable, for, he says, bears rarely eat walrus and there is no evidence that walrus ever eat bears. I do not wish to suggest that a bear — walrus — bear cycle is the main cause of trichinosis in either species, but it cannot at present be dismissed as an insignificant factor. Admittedly, direct evidence that walrus eat bear meat is lacking, but according to Fay (Table 1) only 201 walrus stomachs containing food have been examined, and the incidence of trichinosis in bears is so high that the eating of bear meat by walrus could be a most unusual occurrence and yet be an important factor in the cycle.

According to the Southampton Eskimos and my own observations, there is usually a live bear on Walrus Island and not infrequently one or two dead ones. The Eskimos consider that the latter die after having been wounded by walrus. Freuchen (Ref. 4, p. 109) also found a bear that had been killed by a walrus, and Giaeever⁷ gives a graphic though secondhand account of a herd of walrus killing a bear in the water. It is reasonable to suppose that pieces were eaten by those walrus that were carnivorously inclined. That walrus will eat large animals other than seals is attested by Pond Inlet Eskimos, who observed one feeding on a live Greenland shark⁸. On the other hand, if bears are attracted to Walrus Island by the walrus, it is probable that they occasionally succeed in killing one⁹. They also must frequently find walrus carcasses washed up on shore or floating

among the ice, as the thick hide of the walrus delays disintegration and escape of the gas that floats them. One instance was recorded in October 1937, when Southampton Eskimos found eight bears feeding on a single walrus carcass at East Bay.

In support of his hypothesis that seals are the main source of *Trichinella* infection in polar bears Fay observes that the frequency of infection in the Alaskan polar bear is twice that of those in Greenland where ringed seals are rarely infected. However, it is apparent from his Table 3 that only three infected ringed seals have been found: one in Greenland out of 1561 examined, and two in Alaska out of 300 examined. The difference in incidence is not significant ($P=0.11$) at the 5 per cent level. Moreover, the same table shows that the infection rate for bearded seals is approximately equal in Greenland and Alaskan waters. On the other hand, the difference between the infection rate in the polar bear for the two areas is highly significant ($P<0.001$), and in our present state of knowledge it seems more reasonable to suppose that this difference is caused by some item in the diet of the western bears than by an unexplained and possibly non-existent difference in the incidence of trichinosis in seals.

Since the original draft of these comments was submitted to the Editor I have had the advantage of considerable correspondence with Dr. Fay. As a result some parts of my note have been amplified and documented. Fay has drawn my attention to his reservations regarding Table 1 and has pointed out that the same reservations apply to the other tables. These tables cannot therefore be considered random samples of populations, and thus no firm conclusions can be drawn from them. This applies to both bears and seals, and the apparent differences in the incidence of trichinosis in Alaska and Greenland animals may be the result of differences in the average age of the samples. However, in the case of the bears the bias would have to be large. Perhaps, as Fay suggests, I have read more definite conclusions into his hypotheses than he intended. Cer-

tainly my own comments and suggestions are extremely tentative. Moreover, I have little doubt that seals are an important source of infection in bears; only further work can tell if they are the most important source. One point on which I am sure we both agree is the need for more comprehensive studies on the food habits of bears and other northern animals. Most of the references given here are vague and have little quantitative value. It is also obvious that records of *Trichinella* infection in animals now known to be susceptible are of small value unless full data, including age, sex, and negative as well as positive observations are recorded and published.

T. H. MANNING

¹ Armstrong, A. 1857. A personal narrative of the discovery of the North-West Passage. London: Hurst and Blackett. p. 330.

² Sverdrup, Otto. 1904. New Land. London: Longmans, Green. Vol. 1, p. 444, 451.

³ Stefansson, V. 1921. The friendly Arctic. New York: Macmillan Co., p. 479.

⁴ Freuchen, P. 1935. Rept. Fifth Thule Exped. Copenhagen: Gyldendal. Vol. 2, pt. 2, p. 111.

⁵ Van de Velde, F. 1957. Eskimo 45:7.

⁶ Choquette, L. P. E., and A. H. Macpherson, personal communication.

⁷ Giaevers, J. 1958. In the land of the musk-ox. London: Jarrolds, p. 102.

⁸ Johnson, Cpl. J. R., R.C.M.P. Game conditions. In Ann. Rept. 1957-8. Ottawa: Can. Wildl. Service files.

⁹ Loughrey, A. G. 1959. Preliminary investigation of the Atlantic walrus, *Odobenus rosmarus* L. Wildl. Mgmt. Bull. Ser. 1, No. 14, p. 52-4.

SUMMER SCHOOL COURSE IN ESKIMO LANGUAGE AND CULTURE AT THE UNIVERSITY OF ALBERTA

A course in "Eskimo Language and Culture" will be offered in the 1961 Summer School of Linguistics, which is being conducted under the joint sponsorship of the University of Alberta and the Canadian Linguistic Association from July 3 to August 15 on the campus of the University in Edmonton, Alta.

This is the fourth consecutive summer in which a program of linguistic studies will be offered at the University of Alberta. As in previous years the study of aboriginal languages spoken in Canada is stressed while making available at the same time a wide range of courses in descriptive and historical linguistics. The following are included this year:

General Linguistics
General Phonetics
Linguistic Geography
Culture and Language
History of the English Language
Modern English Grammar.

The course in "Eskimo" is essentially an intensive language course that aims at giving the participants an active prac-

tical command of the language. The course will be conducted by an Eskimo language expert with over 7 years of residence among Canadian Eskimos and extensive teaching experience; a native Eskimo will act as informant in the classroom and tape-recorded material will also be available. The new language laboratory of the University will be used in practice sessions. The course is intended for all to whom a knowledge of the Eskimo language is of interest and value.

Further information may be obtained from Dr. Ernest Reinhold, Director, Summer School of Linguistics, University of Alberta, Edmonton, Alta., Canada.

INSTITUTE NEWS

Gifts to the Library

The Institute Library acknowledges with thanks gifts of books and reprints from the following persons and organizations:

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Trans-Antarctic Expedition

U.S. Antarctic Projects Officer

U.S. Department of Health, Education, and Welfare. Public Health Service

U.S. Geological Survey

Annual Meeting of the Board of Governors

The Annual Meeting of the Board of Governors was held in Washington on December 10, 1960. The following were elected for 1961:

Officers of the Board: Chairman, Commander David C. Nutt, Dartmouth College, Hanover, N.H.; Vice-Chairman, Dr. F. Kenneth Hare, McGill University, Montreal, P.Q.; Secretary, Dr. J. Tuzo Wilson, O.B.E., University of Toronto, Toronto, Ont.; Treasurer, Commodore O. C. S. Robertson, Canadian Joint Staff, Washington, D.C.

Governors elected by the Fellows of the Institute: Dr. F. Kenneth Hare, McGill University, Montreal, P.Q.; Commodore O. C. S. Robertson, Canadian Joint Staff, Washington, D.C.; Dr. Hugh M. Raup, Harvard Forest, Petersham, Mass.

Governors appointed by the Board: Dr. W. S. Benninghoff, University of Michigan, Ann Arbor, Mich.; John C. Case, Near East College Association, New York, N.Y.; Dr. Richard P. Goldthwait, Ohio State University, Columbus, Ohio; Duncan M. Hodgson, Montreal, P.Q.; Dr. W. E. Van Steenburgh, Dept. of Mines and Technical Surveys, Ottawa, Ont.

Retiring Governors: Dr. J. McT. Cowan, C. M. Drury, Colonel Gerald Fitzgerald, Dr. C. S. Lord.

Man Living in the Arctic

A significant conference on the subject "Man living in the Arctic" was held at the U.S. Quartermaster Research and Engineering Command at Natick, Mass. on December 1 and 2, 1960. The conference was sponsored jointly by the U.S. Army Quartermaster Corps, the U.S. National Academy of Sciences—National Research Council, and the Arctic Institute of North America.

The Quartermaster Corps has made many important contributions to the art of civilized man living and working in the Arctic. It has pioneered in the development of clothing, food, and shelter, as well as in determining the environ-

mental conditions. The conference was dedicated to a review of accomplishments, an examination of new scientific avenues, and forecast of future living requirements in the Arctic.

The conference was divided into four half-day sessions, one each on the following subjects: — The Arctic, Contributions of the Quartermaster Corps to Man living in the Arctic, Scientific approaches to solving the problems of man living in the Arctic, and The expanding utilization of the Arctic.

Between the morning and afternoon sessions on the first day the Arctic Environmental Test Chamber at the Quartermaster Research and Engineering Command was dedicated to Sir Hubert Wilkins by Major General A. T. McNamara, Quartermaster General. General McNamara said that "Sir Hubert Wilkins served as a consultant and geographer for the U.S. Army Quartermaster Corps from 1942 to his death in 1958. During this time he made significant contributions to the utilization of our armed forces in arctic areas, for which he was honoured three times for outstanding civilian service to the Government of the United States."

On the evening of December 1 a dinner in honour of American Pioneers of Arctic Exploration was held at the Museum of Science in Boston. Lowell Thomas was master of ceremonies. The following pioneers were specifically honoured: — Kane, Hall, DeLong, Greeley, Brainard, Peary, McMillan, Bartlett, Stefansson, Wilkins, Byrd, Balchen, Eielson, and Ellsworth. McMillan, Stefansson, and Balchen were present.

The Arctic Institute played a large part in the conference. In addition to being one of the sponsoring organizations it assisted in the planning and was responsible for the last half-day session. Dr. Paul A. Siple, a governor of the Institute, was general chairman of the conference. The Executive Director and Dr. Walter A. Wood each acted as chairman for a session. The last session included three papers: — one on the Utilization of the Arctic's Natural Resources by Paul Queneau, a governor of the Institute; a second on Human Society in the

Arctic Today by Professor Trevor Lloyd, also a governor; and a third on the Role of Government in Arctic Expansion by Dr. George Rogers, a member of the Institute staff.

JOHN C. REED

Review of the Arctic Environment

With the support of a grant from a United States Army source the Arctic Institute is engaged in a comprehensive analysis of the environmental factors affecting operations in the polar basin. A full report is planned for completion in the fall of 1961. The study has been organized by the Institute staff and to John Sater has been assigned the re-

sponsibility for the preparation of the report. An advisory committee of about 25 specialists, mostly outstanding Canadians and Americans, has been organized to ensure full coverage and authoritative material.

Operations, for the purposes of the study, are the organization, control, maintenance and support, movement, and communications of people. Thus, the review is expected to point out the capabilities and limitations of man in the Arctic and to appraise the status of environmental knowledge in order to indicate research needed to increase operational capabilities.

JOHN C. REED

ELECTION OF FELLOWS

At the Annual Meeting of the Arctic Institute held at Washington on December 10, 1960 the following were elected Fellows of the Institute:

Dr. Carl S. Benson, Dept. of Geology and Geophysics, University of Alaska, College, Alaska.

Dr. Børge Fristrup, Geografiske Institut, Copenhagen, Denmark.

Dr. B. G. Craig, Geological Survey of Canada, Ottawa, Ont.

Dr. J. A. Fraser, Geological Survey of Canada, Ottawa, Ont.

Mr. J. Keith Fraser, Geographical Branch, Dept. of Mines and Technical Surveys, Ottawa, Ont.

Superintendent W. G. Fraser, G. Division, Royal Canadian Mounted Police, Ottawa, Ont.

Dr. W. W. Heywood, Geological Survey of Canada, Ottawa, Ont.

Dr. Kjeld Helmen, Botanical Institute, University of Copenhagen, Copenhagen, Denmark.

Dr. Eric Hultén, Riksmuseum, Stockholm, Sweden.

Mr. John P. Kelsall, Canadian Wildlife Service, Ottawa, Ont.

Dr. A. W. Mansfield, Fisheries Research Board, Montreal, P.Q.

Dr. F. Müller, Geography Dept., McGill University, Montreal, P.Q.

Dr. Norman J. Oliver, Air Force Cambridge Research Center, Bedford, Mass.

Mr. John A. Pihlainen, Ottawa, Ont.

Dr. George P. Rigsby, U.S. Navy Electronics Laboratory, San Diego, Calif.

Mr. William E. Taylor, National Museum of Canada, Ottawa, Ont.

Dr. Donald E. Wohlschlag, Stanford University, Stanford, Calif.

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